

THE SIDEREAL MESSENGER.

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THE SIDEREAL MESSENGER,

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ELEMENTARY PRINCIPLES GOVERNING THE EFFICIENCY OF SPECTROSCOPES FOR ASTRONOMICAL PURPOSES.

JAMES E. KEELER.

FOR THE MESSENGER.

The exact determination, by analytical methods, of the size and disposition of the parts of a spectroscope which shall best adapt it to any one of the numerous purposes for which this instrument is used in astronomy, is not generally possible, since practical considerations, not amenable to mathematical treatment, materially modify the results of theory. As in many other instruments, the adopted form is frequently a compromise between conflicting requirements. Nevertheless, sufficiently broad principles may be stated, which will serve as guides in estimating the efficiency of any form of spectroscope for its intended purpose. The effect of the practical considerations which have been alluded to can best be studied by seeing how they effect the several requirements deduced from purely theoretical considerations. The object of the present article is to state the principles of efficiency in an elementary manner, and illustrate their application, for the benefit of students who are beginning work in astronomical spectroscopy. It may seem as if they are too obvious, from well-known laws of optics, to require explanation, but examination of printed descriptions of spectroscopic observations will show that they have not been entirely understood, or, at least, not always borne in mind by many practiced observers.* Little apology seems necessary, therefore, for setting forth these principles for the benefit of beginners.

* See Professor Hastings' review of the spectroscopic observations printed in Vol. XLI. *Memoirs of the R. A. S.*, in the *Report of the Eclipse Expedition to Caroline Island, May, 1883*. I may perhaps be also allowed to instance certain criticisms of my own spectroscopic work, at the meeting of the Royal Astronomical Society on May 8, 1891, as reported in the *June Observatory*.

In considering such matters relating to instruments as are not theoretically determinate, I have had to rely largely on individual experience, which may be at variance with that of other observers. Statements to which this explanation applies will generally be easily recognized.

With a few exceptions, which will be considered later, the spectroscope for astronomical purposes is always used in connection with a telescope. The simplest possible combination is a prism placed in front of the object-glass of a telescope. This form of instrument has great advantages for certain kinds of work, as everyone who is familiar with the wonderful results obtained at Harvard College Observatory will recognize, but it is limited in its application, and it is expensive, since the prism, if no light is lost, must be large enough to cover the full aperture of the telescope objective. Its greatest disadvantage is that it does not allow the use of a comparison spectrum. As it is not likely that the student will have occasion to use a spectroscope of this kind, it will not be considered further here.

The most common, and most generally useful form of spectroscope for astronomical purposes, is the compound spectroscope, consisting essentially of slit, collimating lens, prism or other dispersive member, and observing telescope. It is seen in its simplest construction in the small spectroscopes used in chemical laboratories for the analysis of minerals.

The functions of the different parts of the compound spectroscope may be briefly explained as follows: The collimating lens serves to form a virtual, erect image of the slit at an infinite distance, and this image, the brightness of which determines the brightness of the spectrum, may be viewed directly with the observing telescope in the same way as a distant object. If the image is monochromatic (that is, if the slit is illuminated with monochromatic light), the action of a prism placed, in the position of minimum deviation, so as to intercept the rays from the collimator, is simply to displace the image through a certain angle, without changing in any way its magnitude, shape, or (neglecting loss of light by reflection and absorption) its brightness. If the image emits light of different but determinate wave-lengths, each set of parallel rays is displaced through a different angle,

forming a series of monochromatic images of the slit, or bright-line spectrum. As long as these images are separated in the field of the observing telescope, the brightness of the spectrum will depend solely on the brightness of the primary image, any change in the width of the slit making a corresponding change in the width of the lines without changing their brightness.* The case is different if the images overlap so as to form a continuous spectrum. The brightness is then proportional not only to the brightness of the primary image, but also to the width of the slit. The *purity* of the spectrum, or exactness with which the rays of slightly different wave-length are separated, also depends, down to a very small limit, upon the width of the slit, to which it is *inversely* proportional. To get a bright spectrum, the slit must be wide; to get a pure spectrum the slit must be narrow. In any practical case, experiment shows what compromise is most advantageous.

When different spectroscopes are compared, the width of the slit must be taken to be its width in angular measure, as seen from the optical center of the collimating lens.

The laws which govern the brightness of the spectrum as seen in the observing telescope under different magnifying powers are the ordinary laws of the brightness of telescopic images. The highest power P which will give the maximum brightness is obtained by dividing the aperture of the observing telescope by the aperture of the pupil of the eye. If the latter is taken to be one-fifth of an inch, the value of P will be five times the aperture of the observing telescope in inches. In practice a better result will be obtained with a power of seven or eight for each inch of aperture. For any magnifying power p greater than P the brightness is proportional to $\frac{P^2}{p^2}$.

When the compound spectroscope, the principles of which have been briefly considered above, is used in connection with an equatorially mounted telescope, two different telescopes form parts of the apparatus; namely, the great telescope of the equatorial and the telescope of the spectro-

* Provided the angular width of the slit is greater than the angle subtended by one wave-length of light at a distance equal to the collimator aperture.

scope. To avoid confusion they will be distinguished by the terms telescope and observing telescope, respectively.

The spectroscope is mounted in such a way that the axis of the collimator is coincident with the axis of the telescope, and the slit is brought into the focal plane of the great objective. An image of any distant object to which the telescope is pointed is therefore formed upon the slit-plate. Certain limitations are then imposed upon the dimensions of parts of the spectroscope.

The first condition to be fulfilled is that the angular aperture, or ratio of linear aperture to focal length, shall have the same value for both telescope and collimator; otherwise, there will be a marginal ring on one lens or the other which will never be used. If the great telescope is of one foot aperture and fifteen feet focal length, the collimator, if of one inch aperture, should have a focal length of fifteen inches. For reasons which will appear further on, it will be advantageous to have the aperture of the collimator lens a little greater than that given by the rule, but in that case we must distinguish between actual aperture and effective aperture. The latter, which is determined by the rule, is the diameter of the emergent beam from the collimator when the telescope is directed to a star, and a marginal ring on the lens receives no light from the telescope objective. A cap may be provided to cover this ring, so that the actual and effective apertures can be made the same if desired. In the following discussion it will be assumed that they are the same.

If no light is to be lost, the prisms and observing telescope must be capable of transmitting the cylindrical beam from the collimator. Greater dimensions than those necessary for this purpose would be useless. The effective aperture of the collimator may then also be called the aperture of the spectroscope.

The lens which is placed in front of the spectroscope to form an image of the source of light on the slit-plate (*i. e.*, in the case we are considering, the telescope objective), is ordinarily called the "condensing lens." This name is inappropriate, as it fails to define correctly the function of the lens, and Professor Hastings* has proposed to substitute for it

* *Caroline Island Report*, p. 108.

the term "image lens." As the intrinsic brightness of the image of a surface, the moon for example, in the focal plane of an image lens of constant linear aperture, is inversely proportional to the square of the focal length of the lens, it might seem at first sight as if the spectrum of the surface, when a short-focus lens is used, ought to be brighter than with a long-focus lens of the same aperture. Nevertheless, it is easy to show that the brightness of the spectrum is independent of the angular aperture of the image lens.

To do this let A , F , S , represent respectively the aperture, focal length, and area of the image lens, a , f , s , the corresponding dimensions of the collimating lens. Then as has already been shown, $\frac{A}{F} = \frac{a}{f}$.

Let the source of light be a small uniformly bright surface, and let the unit of light be that quantity which falls upon an area equal to that of the collimating lens. Then the quantity of light which falls upon the image lens is

$$\frac{S}{s} = \frac{A^2}{a^2} = \frac{F^2}{f^2}.$$

All this light falls upon the collimating lens, and is therefore found in the virtual image formed by the latter at an infinite distance; but the angular magnitude of this image is $\frac{F}{f}$ times, its angular surface $\frac{F^2}{f^2}$ times that of the object.* Hence we have $\frac{F^2}{f^2}$ times the light distributed over a surface $\frac{F^2}{f^2}$ times as great, and therefore the brightness of the image is the same as that of the object.

The brightness of the virtual image determines the brightness of the spectrum. We conclude, therefore, from this discussion that the brightness of the spectrum of the distant object is independent of the angular aperture of the image lens. A long-focus telescope is as advantageous for observations of the spectra of the sun, moon and extended nebulae as a short-focus telescope. The efficiency, so far as brightness is concerned, is determined solely by the effective aperture of the spectroscope.

* It will easily be seen that this is true. The collimator lens may be regarded as the eyepiece of a telescope, the magnifying power of which is $\frac{F}{f}$.

To illustrate this result, let us suppose that we have a spectroscope of one inch aperture, with collimator twenty inches long, used in connection with a telescope of one foot aperture and twenty feet focal length. The diameter of the solar image on the slit plate, when the telescope is directed to the sun, will be about 2.2 inches. Let us suppose that the slit-width is adjusted until the spectrum is of satisfactory purity and brightness.

If the spectroscope is now removed and placed upon a telescope of the same aperture but only half the focal length, the image of the sun on the slit-plate will be only 1.1 inches in diameter, and it will consequently be four times as bright; but only one-fourth of the rays passing through the slit fall upon the collimator lens. The spectrum will therefore have the same brightness, and as the slit-width has been unchanged, the same purity as before.

If the collimator is now shortened one-half, all other dimensions being as before, all the rays passing through the slit will fall upon the collimating lens, which must now have a focal length of ten inches; but the slit is now twice too wide, and if narrowed until the original purity is restored, the spectrum will be just as bright as before.

If instead of shortening the collimator to make its angular aperture equal to that of the second telescope, we increase its aperture to two inches (the dimensions of the other parts of the spectroscope being correspondingly increased), the brightness of the spectrum will be increased four times, with the same degree of purity as at first.

Another interesting conclusion, which is a well-known fact in optics, may be drawn from the preceding discussion. Since in determining the brightness of the virtual image F and f may have any values, and since the virtual image formed by one set of lenses may become the object for another set, it follows that by no combination of lenses can we obtain an image of an object which shall be brighter than the object itself.

If an image of the sun is formed by a convex lens, the conditions of temperature and brightness at any point within the image are (neglecting loss of light due to absorption and reflection) the same as if the point were brought to within such a distance of the sun that its disc would sub-

tend the same angle as the lens. The same statement holds good for any other extended surface. We may base upon this a conventional way of regarding the distant source of light which is sometimes useful in determining the brightness of the image upon the slit-plate, namely: we may regard the object-glass as replaced by the luminous surface itself, stretched across the open end of the telescope tube; or we may consider the luminous surface to be just outside the objective, in which case the absorption of the glass is taken into account. This convention leads to the same conclusions as the discussion already given. It can be applied to a consideration of the brightness of the spectrum only when the image is sufficiently large to fill the slit of the spectro-scope.

We have shown that for certain objects a small telescope gives as bright spectra as a large one; indeed, the small one has the advantage, since its object-glass is thinner and absorbs less light. The beginner might then naturally ask why a large telescope is desirable for spectroscopic work. The answer is that for such objects there is no advantage in a large telescope, but all objects which we have to examine are not extended surfaces like the sun and moon.

The case which is furthest removed from that which we have hitherto considered, is that of a star. The image lens may then properly be called a condensing lens, since the brightness of the spectrum, as well as that of the image, will depend on the aperture of the lens. In a stellar image we cannot discriminate between quantity of light and brightness. The spectroscope slit is in all cases so narrow as just to include the image, and all the light of the star goes into the spectrum. Hence increasing the aperture and focal length of the collimator does not increase the brightness, although, as the same slit-width then subtends a smaller angle, it increases the purity of the spectrum.

The other extreme in the character of the source of light is when the angular magnitude of the object is as great as the angular aperture of the telescope. Seen from the slit, such an object would completely fill the opening occupied by the object-glass, and the removal of the object-glass would increase its apparent brightness. The brightness of the sky spectrum, for instance, is greater when the object-glass of a

telescope is removed. It is obvious that for such objects better results can be obtained without a telescope.

A practical case of this kind occurs in astronomy. For observing the spectrum of the aurora, or of the zodiacal light, no telescope should be used. The aperture of the spectroscope should be as large as possible, and (from considerations of convenience and portability) the collimator and observing telescope should be short.

The same construction may be extended to meet the case of bodies of no larger angular magnitude than the sun and moon. If the angular aperture of the collimator is $\frac{1}{2}^\circ$, i. e. if the focal length is 115 times the aperture, the solar spectrum obtained with a given spectroscope when the collimator is pointed to the sun is the brightest possible. The telescope or image lens is here dispensed with. Considerable advantage may sometimes be gained by applying this principle, particularly in laboratory work where a heliostat is used, and where the use of a long collimator is attended with no inconvenience. In measures of the heating effect in different parts of the spectrum, for which rock-salt lenses and prisms are used, the saving of an additional lens is a matter of some importance.

It will be noted that a spectroscope of this construction is necessarily an *integrating* spectroscope, and it cannot be used to study the spectrum of any particular part of the luminous source. An attempt to apply the same principle to the other heavenly bodies presenting sensible discs would be rendered futile by the excessive length of collimator required.

We have still to consider the case of bodies of small angular magnitude, like the planets.

In this case the image of the object does not cover the entire length of the slit. To form a clear idea of the conditions of efficiency which depend upon the size of the telescope, let us suppose that we have a spectroscope attached to a telescope of considerable size, and have adjusted the slit so as to obtain a satisfactory degree of brightness and purity in the spectrum.

If we now imagine the telescope to become smaller, preserving the same angular aperture, the brightness and purity of the spectrum will remain unchanged, but the width of the spectrum, which is determined by the diameter of the

image on the slit, will diminish. Now the visibility of an object depends upon its size, as well as upon its brightness, and a long line is easier to see than a short one, when the length of either is inconsiderable. The breadth of the smaller image can be increased by means of a cylindrical lens, but only by a proportional sacrifice of brightness. Hence we conclude that for spectroscopic observations of small bodies, such as the planets and their satellites, the head of a comet, and small planetary nebulae, a large telescope is desirable.

We come now to the consideration of more complex sources of light. One of the most interesting cases is that of the solar prominences, in which we have luminous bodies emitting light of definite wave-lengths, ordinarily invisible on account of the glare from the brilliant white light of the sky. The most obvious method for making the prominences visible in the spectroscope is to weaken the continuous sky spectrum by employing a high dispersion. If the object were simply to see the bright lines of a prominence, the same end might theoretically be attained by using a narrow slit, for narrowing the slit diminishes the brightness of the continuous spectrum without altering that of the bright lines. The slit might then, however, be so narrow that the bright lines would be invisible on account of insufficient breadth. By using a spectroscope of greater aperture and a higher magnifying power the slit would not have to be so narrow, and the lines might be seen, but it is evident that the size of the spectroscope to fulfil these conditions, when the bright lines are relatively faint, might transcend all practicable limits. Moreover, we desire to see the whole prominence, and hence must use a wide slit. The only available method, then, is to use a very high dispersion.

On account of the smaller image of the prominence when a short telescope is employed, and consequently smaller slit-width required, a telescope of moderate dimensions is more suitable for observing prominences than a large one.

Another case of extreme interest is that of the corona. The conditions of efficiency for an instrument to be used in observations of the corona during a total eclipse have been determined by Professor Hastings,* who has shown that for such observations a spectroscope with large aperture is required.

* *Caroline Island Report*, p. 110.

The necessity of a large aperture will appear from the following considerations. The spectroscope must be capable of showing dark lines in a continuous spectrum, as well as bright lines on the same background. We have just seen that sufficient contrast between the light of the bright lines and that of the continuous spectrum can be obtained by using a high dispersion with wide slit, or by using a spectroscope of large aperture (and correspondingly high magnifying power) and a narrow slit. Now dark lines cannot be seen with a wide slit, *i. e.*, a slit whose angular width exceeds a few minutes of arc; hence to show dark lines as well as bright lines in a continuous spectrum we must use the second of the two methods just mentioned. From a review of numerous reports of observations of total eclipses, Professor Hastings concluded that an aperture of less than half an inch was ill suited for observations of the corona, while anything over three-quarters of an inch, if properly designed in other respects, would make an effective instrument.

I have found the bright lines in the spectra of some stars to become invisible if more than a very moderate dispersion is used, probably because they are really somewhat diffuse bands, which widen with increase of dispersion.

The conclusions which we have so far reached, relating to the efficiency of the telespectroscope, may now be summed up, as below. It should be noted that they are based upon the principles of common geometrical optics, it being assumed that they are not carried to the limit at which a consideration of the finite length of a light wave is necessary.

A. 1. In all cases the collimator should have the same angular aperture as the telescope.

B. When the object observed is a luminous surface of considerable angular magnitude, such as the sun, moon or a large nebula:

2. The brightness of the spectrum is independent of the angular aperture of the telescope.

3. The brightness is independent of the linear aperture of the telescope.

4. The efficiency of the spectroscope as regards brightness is determined by its aperture, *i. e.*, by the effective aperture of the collimator, the other parts of the instrument being of

such dimensions as to transmit a beam of the same diameter.

C. When the object is of very large angular magnitude, as the sky illuminated by sunlight, the aurora, or the zodiacal light:

5. The spectra of objects whose angular magnitude is greater than the angular aperture of the telescope are best observed without a telescope.

6. The efficiency of a spectroscope for such objects, so far as brightness is concerned, depends upon the aperture of the spectroscope.

7. The same method may be extended to the sun and moon by using a sufficiently long collimator.

D. When the object is a star:

8. The brightness of a star spectrum is proportional to the area of the telescope objective, and independent of the aperture of the spectroscope.

9. The purity of the spectrum is proportional to the length of the collimator.

E. When the object is a body of but small angular magnitude, such as a planet, head of a comet, satellite, small nebula, sun-spot, etc.:

10. For spectroscopic observations of such small objects a large telescope is desirable.

F. The case of the solar prominences seen in full daylight:

11. A spectroscope of high dispersive power should be used for observing the solar prominences.

12. A telescope of moderate dimensions is more suitable than a very large one.

G. The case of the corona during a total solar eclipse:

13. A spectroscope of large aperture with an observing telescope of correspondingly high magnifying power is most efficient for seeing both bright lines and dark lines in the continuous spectrum of the corona.

As remarked at the beginning of this article, the principles just summarized cannot be applied with mathematical exactness. The conditions of efficiency are different, for instance, for large and for small surfaces; but the dividing line between large and small surfaces cannot be sharply drawn. In this respect the rules which have been given do not differ from many others occurring in physical science,

which, notwithstanding their limitations, are correct and useful in their broad application.

We may now consider the practical bearing of these principles on the construction of spectroscopes. The size of the telescope may be left out of the question, as this is usually fixed by other considerations, independent of the use of the spectroscope. An aperture of less than ten inches, however, will hardly be sufficient for studying the spectra of stars.

On referring to the principles which have been established it will be seen that a large aperture is one of the conditions of efficiency for nearly every kind of spectroscope. The same condition will also in a great measure determine the size and weight, and hence also the cost of the instrument. As the prisms must be of such size as to transmit the emergent beam from the collimator, and as their weight varies as the cube of their linear dimensions, the aperture cannot be made very great without making the instrument unmanageable; it is therefore necessary to use a moderate aperture, and a number of small prisms instead of one large one, notwithstanding the theoretical advantage of the latter. An aperture of one inch, which with a telescope of ordinary construction will imply a focal length for the collimator of about fifteen inches, may be taken as suitable for a twelve-inch telescope. For larger telescopes the aperture of the spectroscope may be increased, but for even the largest it is likely that a spectroscope of much over two inches aperture would, if sufficiently rigid, prove to be too heavy a burden. The case of grating spectroscopes is somewhat different, increase in the size of the grating not being attended with increased weight and absorption of light, while the efficiency of the instrument becomes much greater.

Experience seems to show that the most effective form of prism for star spectroscopes is the compound, or Rutherford prism, made up of a heavy flint glass prism with a large refracting angle (usually 90°), and two crown glass prisms cemented one on each face of the flint glass with Canada balsam. Without the two small prisms light could not be made to pass through the large one.

The investigations of Lord Rayleigh throw some doubt on the generally accepted superiority of the compound prism. The greater refracting angle and length of base

which may be given to the flint glass seem to be a hardly sufficient compensation for the negative effect of the crown glass. One definite advantage that may be stated is that very heavy flint glass, which is subject to oxidation on exposure to the air, may be used in the construction of the compound prism, as the perishable flint glass is protected by the hard crown. For photographic purposes such very dense flint is highly objectionable, as it has a strong yellow tinge.

A compound prism used on the large star spectroscope of the Lick Observatory has a dispersive power more than three times as great as that of a single 60° prism of white flint glass.

Two compound prisms are used in the Potsdam spectrograph for determining the motions of stars in the line of sight. It is not likely that a greater number could be used advantageously in eye observations.

The half-prism which is sometimes used for astronomical purposes, has a number of disadvantages as compared with the form just described. The purity of the spectrum is not so great as with other prisms giving the same dispersion; the emergent beam is laterally displaced, and if, as usually is the case, the observing telescope is in line with the collimator, the spectrum is formed by eccentric pencils, increasing the difficulty of avoiding errors of parallax and other small displacements; when several prisms are used, the emergent beam becomes very narrow, and only a correspondingly small part of the objective of the observing telescope is used, greatly to the detriment of good definition. The direct view is also a disadvantage in observing objects near the zenith, which are otherwise most favorably situated. On these grounds, and perhaps some others, preference should be given to the Rutherford prism.

For faint objects giving a continuous spectrum a high dispersion cannot be used, and the spectroscope should therefore be arranged to carry a single 60° prism.

When only a single prism, either simple or compound, or a grating is used, the observing telescope can be made to point to a center of motion which is in the prolongation of the collimator axis and in the axis of the deviated ray. With more than one compound prism the beam of light is

displaced laterally so far that either the center or the position of the observing telescope must be changed. Thus if a great range of dispersive power is required, the construction of the instrument is considerably complicated, but in a first class instrument designed for various kinds of work such an arrangement is necessary. When the train of four compound prisms is used on Professor Young's new spectroscope, the observing telescope is held by a pair of brackets, the necessary rigidity being secured by a brace extending to the upper end of the collimator.

For solar work a diffraction grating will generally be used, the loss of light as compared with a prism train being in this case of no importance. I have recently shown * that a grating can also be used to great advantage in observations of nebulae giving a bright line spectrum. For observation of stars with a grating a very large telescope aperture is necessary. But for the remarkable brilliancy of the gratings which in the last few years have been ruled by Rowland on surfaces prepared by Brashear, such observations would be quite impossible.

The objectives of the collimator and observing telescope should preferably be made of Jena glass, as such objectives when properly corrected have so little chromatic aberration that all parts of the spectrum except the extreme ends have practically the same focus. No adjustment of the observing telescope is required in passing from one part of the spectrum to another, an advantage which adds greatly to the convenience as well as to the accuracy of the observations. To diminish the loss of light by reflection, the object-glasses if small, (as they always are in a star spectroscope) may be cemented with Canada balsam.

It is usual to make the collimator and the observing telescope of the same focal length. If, however, the collimator is unusually long, say twenty inches or more, the most effective eyepiece for an equally long observing telescope must have an equivalent focal length of several inches, and this, according to my experience, is undesirable, if precise measurements are required, on account of the effect of changes in the accommodation of the eye. I therefore prefer a shorter

* *Publications of the Astronomical Society of the Pacific, No. 11.*

observing telescope and deeper eye-pieces to obtain the same magnifying power. Ten or twelve inches is a convenient focal length. These remarks obviously apply only to visual observations, and they do not apply to solar spectroscopes, on which much higher magnifying powers are used than that which gives the maximum brightness.

The eyepieces of the observing telescope should be achromatic, in order to have the micrometer wires as nearly as possible in focus for all parts of the spectrum. It is impossible to fulfil this condition exactly, at least without a specially constructed eyepiece, as the eye itself is not perfectly achromatic.

On account of the imperfect achromatism of the nominally achromatic telescope, the collimator must have a sliding motion in the direction of its length, in order to bring the slit into the focal plane of the rays which form the part of the spectrum under examination. About one inch is a proper allowance for a twelve-inch telescope of the ordinary construction, and for telescopes of different sizes the amount of motion required will be in proportion to the focal length. The position of the collimator in its slide is shown by a graduated scale. If the spectroscope is quite small it may be attached to the draw-tube of the telescope, and the whole instrument moved in or out to bring the slit into the required position.

The slit is an important part of the spectroscope, and it deserves careful attention. Very good mechanical work is required in its construction. It is convenient to have both jaws move equally in opposite directions on turning the slit screw, the center of the slit thus remaining always in the same place. This construction is condemned by Dr. Scheiner in his text book on celestial spectroscopy as only fit for small instruments not intended for accurate measurements. All the devices which he describes are certainly open to objection, but the double-motion slit with jaws actuated by a right and left-handed screw, as made by Brashear and other American instrument makers, is practically free from error. Caution must be observed not to rely too implicitly on the principle of the double-motion slit, as it is only in certain positions of the prism or grating that a spectral line widens symmetrically when the slit is opened.

The arrangement of a diagonal eye-piece for viewing the slit from behind, first described (so far as I know) by Dr. Carl Braun in one of the volumes of the Haynald Observatory publications, is a very useful, and when a large telescope is employed, indispensable addition. With this eyepiece a good view of the object to which the telescope is directed can be obtained on widening the slit, and on narrowing the slit the observer can assure himself that the exact part of the image which he wishes to examine spectroscopically is within its jaws. The eyepiece should move between stops, so that when fully in the slit may be in the center of the field, and when withdrawn the rays from the slit may pass without obstruction. An equivalent focal length of about one inch will give a convenient magnifying power.

The positions of unknown lines in the spectrum of a heavenly body are determined by comparing them with known lines, usually furnished by a terrestrial source, such as an electric spark passing between metallic points, a spectrum tube or a flame. In order to make the comparisons reliable there must be no displacement of any kind in the comparison spectrum; that is, a line in the spectrum of light coming through the telescope must fall at precisely the same place as the same line in the spectrum of light which is reflected into the slit from the artificial source. It seems to me that this coincidence is best assured, apart from good workmanship in the instrument, by making the light from both sources traverse the instrument under identically the same conditions. In some of the earlier spectroscopes light from the electric spark was reflected from a plane mirror to a totally reflecting prism directly over the slit and thence into the collimator; but this is a bad arrangement, since the spark, being of very small dimensions and at some distance from the slit, sends light to but a small portion of the collimator lens, while the full aperture of the collimator is filled with light from a heavenly body. An *image* of the spark should be formed on the slit by a lens having a greater angular aperture than the collimator, so that the light from the spark, after being reflected through the slit in the direction of the collimator axis, will completely fill the aperture of the collimator. If the actual aperture of the collimator

is greater than the effective aperture, it should be reduced by a stop until equal to the effective aperture, as recommended in the first part of this article. If very accurate comparisons are necessary, as in measures of the motions of stars in the line of sight, all the optical parts of the instrument must be perfect, and all the adjustments must be made with the greatest care. The latter condition, it is, of course, the business of the observer to fulfil. In a paper on the motions of the planetary nebulae in the line of sight, I have described briefly the arrangement of the slit and comparison apparatus of the large spectroscope of the Lick Observatory, which leaves little to be desired in the way of convenience and accuracy.

In spectroscopes for observing solar prominences the slit plate is frequently movable in a direction at right angles to the slit, as the adjustment of the slit on the limb of the solar image is a delicate one, not easily made with the slow motions of the equatorial. This construction is not to be recommended for other purposes.

When the spectrum of a star is observed, a cylindrical lens is placed in front of the slit to give the spectrum sufficient breadth. The way in which a cylindrical lens is used will appear from the following considerations:

When a convex cylindrical lens is placed in the cone of rays from the object glass two real, linear images are formed by the combined action of the two lenses. The one nearer to the cylindrical lens is called the principal focal line. Its axis is parallel to the axis of the cylindrical surface of the lens, and its length is equal to the diameter which the cone of rays will have at that point if the cylindrical lens were removed. Its distance from the focal plane of the telescope and from the cylindrical lens depends upon the focal length of the latter.

The linear image farther from the cylindrical lens is called the secondary focal line. Its axis is perpendicular to the axis of the cylindrical lens, and its length depends upon the focal length and position of the cylindrical lens. The secondary focal line is always in the focal plane of the objective, and it is therefore the more convenient one to use. It must be made to fall precisely within the jaws of the slit, and in making this adjustment the diagonal eyepiece al-

ready described is almost indispensable. The breadth of the spectrum, which is evidently equal to the length of the line, can be varied by simply changing the distance between the lens and the slit.

The focal length of the cylindrical lens is not entirely an indifferent matter. If the rays passing through the slit are widely divergent, they will fall outside the limits of the collimator lens, and some light will be lost. Hence the cylindrical lens should have a considerable focal length, say ten or twelve inches. The emergent beam from the collimator will then be elliptical in section, with the longer axis parallel to the slit, and a stop may be cut so as to just allow the passage of the beam, and placed over the collimator lens when the comparison apparatus is used. It should be noted that the *minor* axis of the emergent beam is equal to the effective aperture of the collimator; hence unless the actual aperture is somewhat greater, some light will be lost.* The advantage of a collimator aperture somewhat in excess of the requirements of the rule given in the summary under A has already been mentioned. As prisms are almost invariably higher than necessary to transmit a cylindrical beam, no change in their dimensions need follow the enlargement of the objectives of the collimator and observing telescopes.

For measuring the positions of lines in the spectrum a great many devices are used, such as a graduated circle read by microscopes or verniers, and a micrometer slow-motion screw for moving the observing telescope. The illuminated scale reflected from the first surface of the prism, commonly used on small spectroscopes for analyses of minerals, is one of the roughest devices for recording the position of lines. It is not necessary that the positions should be read in terms of any determinate unit. It is not necessary, for instance, to eliminate eccentricity from the readings of a graduated circle by reading opposite verniers, (unless *deviations* are required for other purposes), since the correction for eccentricity is itself a continuous function of the circle reading. I have no doubt that if an instrument of given weight and cost is to be designed so as to give the greatest accuracy of

* The same remarks apply to the case when a considerable length of slit is used, as in observing any extended surface, the cylindrical lens being dispensed with.

measurement, the end will best be reached by relying entirely upon the use of the comparison apparatus and eyepiece micrometer, and using a graduated circle, if at all, only as a finder. The cost and weight of all other attachments can then go into the important parts which determine the efficiency of the instrument.

No reference has yet been made to the *resolving power* of a spectroscope, or its power of separating close lines in the spectrum. Lord Rayleigh has shown that for simple prisms the resolving power depends upon the difference between the longest and shortest paths of rays in traversing the prisms. With properly constructed apparatus the extreme difference of paths will be the sum of the bases of the prisms. A single prism is therefore equal in resolving power to two prisms of half the size. Hence we see that the power of a spectroscope is by no means defined by its dispersion, for it is easy to obtain large dispersion with small resolving power. It is customary to state the optical power of an instrument in terms of the number of simple prisms required to give the same dispersion, and although the statement is indefinite, yet, as prisms for astronomical spectroscopes are generally of about the same size, it is accurate enough for conveying a general idea of the efficiency of the apparatus employed.

The relation between thickness of glass and the resolving power of a prism is quite analogous to that between aperture and separating power of a telescope objective.

For compound prisms the rule for resolving power requires modification, a given thickness of the less dispersive medium (crown glass) not counting for so much as the same thickness of flint glass.

The equations of Lord Rayleigh show that a prism of dense flint glass must have a base of at least one centimetre in order to separate the *D* lines. If the student wishes to test this result by actual experiment, let him place a cardboard stop with an aperture of about one-tenth of an inch over the collimator of his spectroscope when the telescope is directed to the sun. If not more than two simple prisms are used, he will find that with no adjustment of the apparatus can he separate the *D* lines, although there may be abundance of light. A long slit one-tenth of an inch wide may be used instead of a circular aperture, provided it is placed

parallel with the refracting edge of the prism, and not cross-wise.

The resolving power of a grating depends on the number of lines used on the grating and on the order of the spectrum. It is the same in all parts of the spectrum of one order, whereas the resolving power of a prism increases very rapidly toward the violet, where it is seven or eight times as great as in the red.

Professor Schuster takes as the unit of resolving power that power which is necessary to separate lines differing by the thousandth part of their own wave-length. A spectrum in which such lines can just be separated has unit purity. The resolving power of a spectroscope is numerically equal to the greatest purity of spectrum obtainable with it.

The *D* lines are very nearly one one-thousandth part of their own wave-length apart. Hence the spectroscope considered above, with a prism one centimetre on the base, would have a resolving power of unity for sodium light. A grating with one thousand lines, would have unit resolving power in the first spectrum.

The great advantage of a grating over a prism in regard to resolving power is apparent from the figures which have been given. A resolving power of 100, which is easily realized in large gratings of modern construction, would theoretically require a thickness of one metre of glass if obtained by prisms, and doubtless it would actually require much more if enough light were left after passing through the prisms to make the experiment practicable.

When there is paucity of light, the full resolving power of a spectroscope cannot be realized.

For efficiency in regard to resolving power a large aperture of the spectroscope is an important condition, as we have shown it to be in most cases from another standpoint, for brightness.

Almost all our space has been devoted to a consideration of the compound spectroscope, as it is the only form with which exact comparisons of spectra are possible. For merely seeing the spectrum very simple spectroscopes suffice. The McLean star spectroscope, which is much used for looking at the spectra of stars, has no slit, and therefore cannot be used for any other purpose. In all instruments of this kind

which I have seen, the spectrum is made unnecessarily wide, and correspondingly weak by using a cylindrical lens of too short focus. A somewhat similar combination of a small direct-vision prism and a cylindrical lens, placed on the eyepiece of a telescope so as to receive the emergent beam, will give good views of stellar spectra.

Such spectroscopes are necessarily of small resolving power, but as the prisms required are very small, but little light is lost by absorption, and they give brilliant spectra.

It has been impossible to mention in this article the optical and mechanical features of the great variety of forms which have been given to the spectroscope, but a fair judgment of the efficiency of any particular form for its intended purpose may be based on the general principles which have been explained. The mechanical execution has much to do with the "efficiency" of an instrument, not in the limited sense in which we have used the term, but in its more usual application. Even mechanical defects which are apparently trivial, such as the division of a micrometer head into any number of parts but one hundred, or the marking of a scale by longer lines in any other way than by fives and tens, by causing annoyance and loss of time to the observer, possibly even mistakes, detract from the usefulness of the instrument. The mechanical appliances should be such as to afford the greatest facility for adjustment and accurate measurement, as well as to give proper support to the optical parts.

A FURTHER NOTE ON STAR-DISTRIBUTION.

W. H. S. MONCK *

FOR THE MESSENGER.

Some years ago I pointed out a formula by which the relative brilliancy of binary stars whose orbits were known and whose light had been measured by a photometer, could be determined. The relative brilliancy thus computed proceeded on the assumption that the stars were in each case globes of the same density. The formula was only strictly correct where the satellite was very small compared with the principal star, but in every case it afforded an approximation

* Dublin, Ireland.

which, in dealing with averages, was quite sufficient for the purpose.

Last year Mr. Gore published a complete catalogue of the binary stars whose orbits had hitherto been computed, giving in each instance the brilliancy according to my formula. The result was to confirm a conclusion which I had already drawn as to the extraordinary difference in brilliancy between different binary stars. Adopting the star ϵ Ursæ Majoris as the unit (its orbit being well determined and the intensity of its light accurately measured both at Harvard and at Oxford) Mr. Gore's figures ranged from 92.99 down to 0.0015. So far, however, the table did not throw much light on the problem of star-distribution; but to this it has recently been extended by Mr. Maunder of Greenwich, in a paper which appeared in *Knowledge* for June, 1891. Mr. Maunder compared the brilliancy of 21 binary stars of the Sirian type, with that of 29 stars of the solar type, obtaining an average of 12.0 for the former against 2.3 for the latter. Reducing this result to the photometric scale I find that a Sirian star whose mass and distance is equal to that of a solar star will, on the average, appear 1.79 magnitudes brighter. In other words if we suppose the mean range of a telescope to extend to stars of the 12th magnitude, it will give Sirians at a distance corresponding to the 12.9th magnitude, while it will stop with solar stars at a distance corresponding to the 11.1th magnitude. Sirian stars will thus be visible at more than double the distance of solar stars of equal mass.

These consequences are important as regards the number of stars of different classes which we can see either with the naked eye or with the telescope. If 50 per cent. of those which we see are Sirians, it does not follow that one-half of the stars are of the Sirian type. We see Sirian stars at distances where the corresponding solar stars are invisible. On the hypothesis of uniform distribution the stars of the $n + 1$ th magnitude should be nearly 4 times as numerous as those of the n th magnitude and 3 times as numerous as all the stars brighter than the $n + 1$ th magnitude. I have pointed out that in using photometric measures this proportion is never realized. 3 and 2 will be found to answer better than 4 and 3, and for the present purpose I shall

adopt them. As a difference of one magnitude makes the stars three times as numerous, a difference of 1.79 magnitudes will make them about seven times as numerous and the Sirian stars visible, either with the naked eye or in any given telescope, will be about five times as numerous as they would appear to be if our eyes and our telescopes had the same space-penetrating power for solar as for Sirian stars.

How far this result can be carried on to red stars I am not in a position to offer any opinion. But I think there is little doubt that their brilliancy is less than that of solar stars and that the space-penetrating power of telescopes for red stars is consequently less than for solar stars. If we could separate the stars included in any given sphere with the sun as centre from those lying outside that sphere, we should probably find the red stars much more numerous than a mere count of the sky would have led us to expect, the solar stars about as numerous as we expected, and the Sirian stars much reduced in number. It is no objection to this conclusion that some Sirian stars have measurable parallaxes and that some bright red stars have not. Stars, no doubt, differ enormously in mass as well as in brilliancy, and no conclusion in which one of these elements has been neglected can be relied on in individual instances.

Mr. Maunder, it should be stated, holds that solar stars are generally speaking of greater mass than Sirian. We shall hardly be in a position to decide this question until the parallaxes of binary stars have been better determined. Greater mass would, of course, act as an equivalent for great brilliancy and the space-penetrating power of our telescopes for both classes of stars might, on this assumption, be nearly identical. Without denying that there are some grounds for Mr. Maunder's opinion, however, I think the supposed greater mass of the solar stars will not explain the whole of the phenomena. Binary stars which can be separated in the telescope and yet revolve in a measurable period must be among our comparatively near neighbors. Mr. Maunder's comparison of these gives 29 solar stars to 21 Sirian. But probably even within these limits of distance there are solar stars which have escaped observation (at least such continuous observation as would be required for the computation of orbits) owing to their faint-

ness, but which would have been observed and computed if promoted to the Sirian rank. The proportion of 58 solar stars to 42 Sirian is thus likely to be under instead of over the mark, at least as regards the nearer stars; whereas on a general count of the sky these proportions would probably be reversed. There is no reason to think that solar stars have a greater tendency to form binary systems than Sirian: indeed for very close doubles which are detected only in eclipse or by spectroscopic variations the evidence points the other way. The subject is well worth following up. One consequence of my theory that Sirian stars are farther from us than solar stars of the same photometric magnitude is that the solar stars of any magnitude will on the average have a greater proper motion than the Sirian while the red stars will probably surpass both. A classification of fast-moving stars—say those with a proper motion of over $0.5''$ per year—according to their spectra would help to solve this problem.

I may remark that this conclusion does not depend on the assumption that the unit of surface is brighter in the case of Sirian than of solar stars. The effect would be the same if Sirian stars were of small density and presented to us a very large extent of illuminated surface relatively to their mass. The phenomena of the Algol type of variables (assuming them all to be Sirian; but I am not aware that the spectra of some of them have been determined) favor this assumption of small density. But small density does not imply small mass, and it seems certain that the mass of some of the nearer Sirian stars exceeds that of the sun. But of course the sun may be a very small solar star. I ought to have noticed that the larger mass of the solar stars assumed by Mr. Maunder might render the computation of orbits more easy by shortening the period of the revolution. Measures of parallax seem here again requisite, though a part of the difficulty might be removed by observations (carried on for some years) of the spectroscopic velocities of the stars in the line of sight. To both parallax-measurers and spectroscopists binary stars offer an interesting field of investigation.

THE HISTORY OF ASTRONOMY.*

G. F. CHAMBERS, F. R. A. S.

Every science has a history, and it will often happen that a due presentation of the facts of that history and a due comprehension of their bearing will greatly aid an intelligent reader in his study of the particular science in its modern aspects. All this is particularly true of Astronomy. A student who has mastered the facts appertaining to its origin in early times, and to its subsequent development down to the present epoch, should have acquired a considerable general knowledge of the science itself as a whole.

Poetry and romance have always talked about the Chaldean shepherds as the first astronomers. I can neither affirm nor deny the idea. But when one considers how much time men of the shepherd class spend out in the open air, and how accurate their anticipations of the weather generally are, it seems not unreasonable to think that such men as the shepherds of Eastern lands may have been in a certain general sense the earliest astronomers.

This conception naturally suggests the question, "Do we find any allusions to astronomical matters in the Holy Scriptures?" To this the answer must be in the affirmative. Of historical events there are two, the astronomical import of which is very obvious: (1) The standing still of the sun and moon, as so stated, at the command of Joshua;† and (2), the going back of the shadow of the sun for King Hezekiah's sake on the dial of Ahaz.‡

The former of these events has never been adequately explained, and it can only be regarded as having been a miracle in the proper sense of the word. With respect, however, to what happened in the case of Hezekiah there seems reason to believe that the observed facts may be reconcilable with the circumstances of a partial eclipse of the sun, visible as such at Jerusalem on January 11, 689 B. C. This eclipse is known to have happened nearly at noon, and if we may suppose the words "dial of Ahaz" to apply to a large gnomon or sundial formed of masonry, and similar in character to

* From *Pictorial Astronomy for General Readers*, June, 1891.

† Joshua x. 13.

‡ II. Kings xx. 11.

such a structure as that which still exists at the ruined Hindû Observatory at Benares, we may understand that a shadow caused by an uneclipsed sun might be brought back on the upper part of the sun's disk suddenly ceasing for an hour or so to be a source of light.*

Passing from Asia into Europe we come to the Greeks, of whom it may be said generally that they were great astronomers as well as physicists. The names of Thales, Pythagoras, Anaximenes, Meton, Eudoxus, Philolaus, Aristotle, Calippus, Archimedes, Aratus, Aristarchus, Eratosthenes, Apollonius and Hipparchus will readily occur to the mind. They were perhaps not all Greeks in the strict literal sense of the word, but may virtually be regarded as such, bearing in mind the school of thought (to use a hideous modern term) to which they belonged. Two or three of those mentioned, such as Thales, Aristotle, and Hipparchus, were giants in science, comparable with the Humboldts and Herschels of the present century. This remark is peculiarly true of Hipparchus. The work which he performed really laid the foundations for the science of exact astronomy as distinguished from mere star-gazing.

The labors of Hipparchus were as varied as they were important. He discovered the Precession of the Equinoxes; was the first to use Right Ascensions and Declinations; probably invented the stereographic projection of the sphere; suspected that inequality in the moon's motion afterwards discovered by Ptolemy and known as the Evection; calculated eclipses; and formed the first regular catalogue of stars in consequence of having observed a temporary star burst forth in 131 B. C.

After the Christian Era the first illustrious name which appears on the pages of Astronomical History is that of Ptolemy of Alexandria, who lived from 100 A. D. to 170 A. D. He was both a writer and an observer. His great work was the celebrated *Μεγάλη Σύνταξις*, better known by its Arabian designation of *The Almagest*. This work contains, among other things, a review of the labors of Hipparchus; a description of the heavens, including the Milky Way; a catalogue of stars; sundry arguments against the motion

* All the details of this are very well worked out in Mr. J. W. Bosanquet's *Messiah, the Prince*, 8vo, London 1869, p. 176, *et seq.*

of the earth, and notes on the length of the year. To Ptolemy we owe the discovery of the Lunar Evection, of the refractive properties of the atmosphere, and of the theory of the universe which bears his name.

It is a remarkable fact that, great as they were in almost every department of life, the Romans utterly failed as men of science. Perhaps it would be more accurate to say that they never tried their hands at physical science. This is the more remarkable when we remember how great they were in everything else. They were great lawyers, great engineers, great statesmen, great generals, great scholars, great poets, great even in medicine and surgery, but as sailors they obtained but moderate success, whilst for physical science they have left us nothing to show.

During the first half dozen centuries of the Christian Era, Alexandria may be regarded as having been the great center whence astronomical knowledge was disseminated throughout the world. But in 640 A. D., the Alexandrian school was broken up by the Saracens under Omar. In the following century, on the building of Bagdad by the Caliph Al-Mansar, that place became the great center of Astronomy, and continued to be such for 400 or 500 years.

The names which have come down to us in this connection are not numerous, but they are individually weighty. Grouping together various writers and workers under the general name of Arabic or oriental astronomers, we fall in with the following: Albategnius, Alfraganus, Al-Sufi, Ebn Yunis, and Abul Wefa. Albategnius (*circa* 880 A. D.) may be regarded as the most distinguished astronomer between Hipparchus and Tycho Brahe. He discovered the motion of the solar apogee, corrected the value of precession and of the obliquity of the ecliptic as previously received, formed a catalogue of stars, and was the first to use sines and chords. Al-Sufi (d. 986 A. D.) was a distinguished Persian astronomer, who left behind him a very curious and interesting catalogue of stars, of which a translation into French was published by Schjellerup at St. Petersburg, in 1874. Ebn Yunis and Abul Wefa both lived about the year 1000 A. D., and greatly developed the use of trigonometry. The latter is thought by some to have discovered the lunar inequality known as the Variation.

In 1079 we find a Persian astronomer of the name of Omar proposing to reform the Calendar by interpolating one day in every fourth year, but postponing to the thirty-third year the interpolation belonging to the thirty-second year. This would have produced an error of only one day in 5000 years, whereas the error arising in the Gregorian Calendar, adopted five centuries later, and which we now use, amounts to one day in 3846 years. The acuteness and research of this Persian philosopher may well excite our surprise and admiration.

The translation of Ptolemy's *Almagest* from Arabic into Latin, and the work done in Spain under the patronage of Alphonso X., King of Castile, indicate a movement of astronomical knowledge in a western direction over Europe. Accordingly the revival of letters, the invention of printing, and the taste for geographical research, cultivated especially by the English, the Portuguese, and the Spaniards, gave a great impulse to the exact sciences, and of course to astronomy amongst them. Hence it follows that work and workers multiply all over Western Europe, Germany taking the lead. The names of several of the famous men of the 16th and following centuries have already occurred in these pages in connection with particular items of work which they did, and with the results which they left behind. It may serve to fix some of these names in the mind of the reader if I enumerate a few of these men, and the centuries in which they died.

During the 16th century we have Regiomontanus, Copernicus, and Jordanus Brunus. The two first were working astronomers in the fullest sense, but Jordanus Brunus was rather a philosophical speculator on astronomical subjects than, strictly speaking, a working astronomer.

In the 17th century we find Tycho Brahe (d. 1601), Fabricius (d. 1616), Kepler (d. 1630), Galileo (d. 1642), Torricelli (d. 1647), Descartes (d. 1650), Gassendi (d. 1655), Hevelius (d. 1687), and C. Huygens (d. 1695). This century produced the first star atlas, by Bayer, a work which constituted a new departure in astronomical records; the refracting telescope; the discovery of spots on the Sun; the discovery of the satellites of Jupiter and of Saturn; observations of transits of Venus and Mercury; pendulum clocks;

the reflecting telescope; the discovery of the progressive transmission of light; and important investigations into the theory of the Moon. In 1666 Flamsteed commenced observations at Greenwich Observatory, and by so doing laid the foundations for that great and prolonged developement of scientific work there which inspired Bessel, half a century ago, to say that if all the books on astronomy in the world, and all the observatories in the world, except Greenwich, were destroyed by some great catastrophe of nature, the whole science could be re-constructed from its foundation by means of the knowledge gathered up and stored at the Greenwich Observatory.

All things considered, the 18th century did not show such an advance over the 17th as the progress of learning and the multiplication of telescopes might have led us to expect. Although Newton lived on till the year 1727, yet he belonged much more to the previous century, his immortal *Principia* having been published as far back as 1687. The first and greatest of the five generations of the Cassini family who have left their mark on French astronomy (Jean Dominique), though he died in 1712, yet performed all his important work (and very important it was) during the second half of the 17th century. The names which should be picked out and attached to the 18th century are only Leibnitz (d. 1716), who was more a mathematician than a scholar, Flamsteed (d. 1719), J. P. Maraldi (d. 1729), Halley (d. 1742), Bradley (d. 1762), La Caille (d. 1762), Ferguson (d. 1776), Pingré (d. 1796), and Le Monnier (d. 1799). A detailed inquiry into the circumstances of the 18th century discloses the general fact that the French came very much to the front as observers and mathematicians; that the Italians to a considerable extent, and the Germans almost entirely, receded into the background; whilst the progress of the English was chiefly in regard to practical matters, such as nautical astronomy and navigation, clocks, chronometers, and time appliances generally, and the construction of astronomical instruments of precision. But we must not pass away from the 18th century without noting two very important points of progress, the invention of the achromatic object-glass by Dollond, and Sir. W. Herschel's success in the manufacture of the reflecting telescopes, and the use of them.

The progress of astronomy during the 19th century has been so absolutely great, that it is quite hopeless to given even a sketch of it. However, nearly all the facts which belong to this century, together with the names of the men, and some of the dates, have already been brought before the reader in previous chapters. The only points which it seems possible to specify are: the great progress in the construction of large astronomical instruments, and the application of photography and of the spectroscope to astronomical purposes. But besides these general points, it is impossible not to be struck with the remarkable growth of the science in England in the hands of amateurs; in Germany in the hands of government establishments; and in America in connection with universities, colleges, and semi-public observatories endowed by deceased benefactors. These are three well-marked national differences of *modi operandi* on which a political astronomer would probably feel inclined to comment at length, and from which to draw moral lessons.

CURRENT CELESTIAL PHENOMENA.

THE PLANETS.

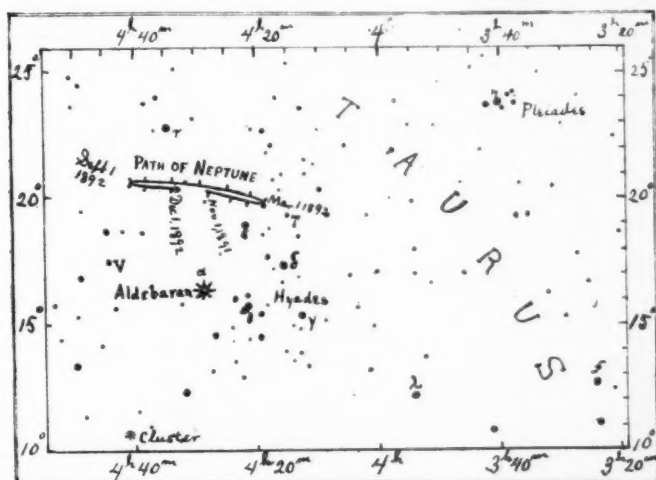
Mercury, having just passed superior conjunction will be for a few days too near the sun to be observed. During the latter half of November daylight observations of the planet may be obtained in the afternoon. During the second week in December, Mercury will be visible to the naked eye about an hour after sunset each evening. The planet will be at greatest elongation east of the sun, $20^{\circ} 36'$, Dec. 11 at 9 A. M.

Venus is moving slowly eastward from the sun, but is at the same time going south so that its position is becoming less favorable to northern observers. Venus and Mercury will be in conjunction, only $1^{\circ} 15'$ apart in declination, Dec. 5 at 9 A. M., central time.

On the afternoon of Oct. 9, the atmosphere being exceedingly transparent and steady, we turned our 16 inch telescope upon Venus, and were able, after half an hour of steady looking, to make out and to sketch some markings on the planet's surface. There was no doubt in the observer's mind that the markings seen were real, but to decide upon their exact form and sketch them correctly was almost impossible. The configuration most easily grasped was that of an irregular wheel, of about two-thirds the diameter of the planet, with four spokes meeting a little south-west of the center of the planet's disk. The magnifying power of the eyepiece used was 400.

Mars is not in position to be observed.

Jupiter is the brilliant star which everyone must notice now toward the south in the early evening. And a grand object he is in the telescope. We have spent several enjoyable hours with this planet during the past month. The new large red spot was on the central meridian of the planet Oct. 8 at $10^h 12^m$ central standard time. Mr. Denning gives the period of rotation of this spot as $9^h 55^m 18.3^s$ or about 23 seconds less than that of the great red spot (*Observatory*, Oct. 1891, p. 329). It is in the same latitude with the dark belt just south of the great red spot, and is perhaps just a darker part of that belt. It was first noticed by Mr. A. S. Williams in June, 1889. There are several white spots in this belt which have the same period of rotation. One of these was on *Jupiter's* central meridian at 8:30 P. M., Oct. 15, following the red spot by a little less than two hours.



MAP SHOWING PATH OF NEPTUNE THROUGH TAURUS.

In the "English Mechanic" for Oct. 2, Mr. Denning has an interesting list of rotation periods derived by different observers from markings in the southern hemisphere, which agree closely together but differ from that of the great spot. We quote them for the benefit of our readers:

h.	m.	s.	Observer.	Remarks.
9	55	17.6	Schröter.	A break in a dark streak, lat. 20° S.
9	55	20	Lohse.	Dark streak, lat. 30° S.
9	55	17.2	Schmidt.	A marking S. of the great S. belt.
9	55	23	Trouvelot.	Grey belt S. of red spot.
9	55	15	Trouvelot.	Grey spot in same zone as last.
9	55	21.6	Williams.	White spot in lat. 30° S.
9	55	11.8	Williams.	Dark spot ditto.
9	55	17.8	Williams.	Dark spot ditto.
9	55	17.9	Denning.	Short belt ditto.
9	55	18.2	Denning.	Bright spot ditto.

The mean of all these is $9^h 55^m 18^s$.

The fine belt on the equator of the planet mentioned last month has been seen on several occasions since that time. It can be seen only when the definition is good; at times the white belt between it and the great southern dark belt seems full of very faint red markings.

Saturn is not in good position yet for observation, but every opportunity should be used to watch the gradual reappearance of the rings during this month. *Saturn* may be observed only in the morning from 3^h to sunrise.

Uranus is behind the sun.

Neptune comes to opposition, Nov. 29. He may be observed during the whole night, and is to be found, in the early evening, toward the east not far from the bright star Aldebaran in the constellation *Taurus*. The accompanying map shows the stars which are visible to the naked eye in that region of the heavens. The two groups of bright stars, the *Hyades* and the *Pleiades* will be easily recognized on any clear night. The fainter stars can only be seen on very dark nights. An opera glass will enable one easily to see all of these and more.

MERCURY.

Date. 1891.	R. A. h m	Decl. ° ' "	Rises. h m	Transits. h m	Sets. h m
Nov. 25.....17	11.0	- 25 12	8 39 A. M.	12 53.1 P. M.	5 07 P. M.
Dec. 5.....18	13.4	- 25 45	9 05 "	1 16.3 "	5 27 "
15.....18	58.6	- 24 03	9 02 "	1 21.9 "	5 42 "

VENUS.

Nov. 25.....17	18.6	- 23 51	8 40 A. M.	1 00.9 P. M.	5 22 P. M.
Dec. 5.....18	13.4	- 24 31	8 58 "	1 16.2 "	5 34 "
15.....19	08.2	- 23 56	9 11 "	1 31.6 "	5 52 "

MARS.

Nov. 25.....13	22.8	- 7 36	3 32 A. M.	9 05.7 A. M.	2 39 P. M.
Dec. 5.....13	46.7	- 9 57	3 26 "	8 50.2 "	2 14 "
15.....14	10.9	- 12 12	3 20 "	8 34.9 "	1 49 "

JUPITER.

Nov. 25.....22	44.3	- 9 24	1 00 P. M.	6 25.6 P. M.	11 52 P. M.
Dec. 5.....22	47.6	- 9 02	12 22 "	5 49.7 "	11 17 "
15.....22	52.0	- 8 33	11 45 A. M.	5 14.7 "	10 44 "

SATURN.

Nov. 25.....11	57.3	+ 2 33	1 27 A. M.	7 40.5 A. M.	1 54 P. M.
Dec. 5.....11	59.9	+ 2 19	12 54 "	7 03.8 "	1 16 "
15.....12	01.9	+ 2 09	12 15 "	6 26.5 "	12 38 "

URANUS.

Nov. 25.....14	06.3	- 12 17	4 35 A. M.	9 49.1 A. M.	3 03 P. M.
Dec. 5.....14	08.4	- 12 28	3 59 "	9 11.9 "	2 25 "
15.....14	10.3	- 12 38	3 22 "	8 34.5 "	1 47 "

NEPTUNE.

Nov. 25.....4	25.0	+ 20 00	4 38 P. M.	12 05.4 A. M.	7 33 A. M.
Dec. 5.....4	23.8	+ 19 57	3 58 "	11 25.0 P. M.	6 52 "
15.....4	22.7	+ 19 55	3 17 "	10 44.4 "	6 12 "

THE SUN.

Nov. 25.....16	04.7	- 20 49	7 10 A. M.	11 47.2 A. M.	4 24 P. M.
Dec. 5.....16	47.8	- 22 25	7 21 "	11 50.8 "	4 20 "
15.....17	31.8	- 23 18	7 30 "	11 55.4 "	4 20 "

Jupiter's Satellites.

Central Time.			Central Time.		
	h	m		h	m
Nov. 16	6 38	P. M.	Dec. 1	6 49	P. M.
17	7 30	"		10 17	"
	9 05	"	2	6 58	"
18	4 27	"		9 43	"
	4 40	"		9 51	"
	7 18	"	4	6 32	"
20	9 20	"		6 38	"
21	6 28	"	5	5 41	"
	7 49	"		10 19	"
	8 47	"	6	7 40	"
	10 07	"	7	4 48	"
22	7 25	"		6 09	"
23	4 36	"		7 07	"
	9 12	"		8 27	"
24	6 17	"	8	5 45	"
	8 26	"	9	9 36	"
25	6 55	"	11	9 16	"
	7 05	"	12	4 27	"
	7 14	"		5 30	"
	9 55	"		6 28	"
	11 06	"		9 42	"
27	11 15	"	13	4 28	"
28	8 23	"		9 36	"
	9 44	"	14	6 45	"
	10 42	"		8 05	"
29	5 43	"		9 04	"
	9 20	"		10 22	"
30	5 11	"	15	7 40	"
	6 31	"			

Configuration of Jupiter's Satellites at 7 p. m., for an Inverting Telescope.

Dec. 1	4 3	0 1 2	Dec. 12	3 4	0 1 2	Dec. 22	3 1	0 2 4
2	4 1	0 3 2 $\frac{1}{2}$		13 3 4 2 1	0	23		0 324 $\frac{1}{2}$
3	2 4	0 1 3	14	4 3 2	0 1	24	2	0 1 3 4
4	1	0 2 4 3	15	4 3	0 2	25	1 2	0 3 2 $\frac{1}{2}$
5	3	0 1 2 $\frac{1}{2}$	16	4 1	0 2 3	26		0 3124
6	3 2 1	0 4	17	4 2	0 1 3	27	3	0 1 4 2 $\frac{1}{2}$
7	3 2	0 4 2 $\frac{1}{2}$	18	4 1	0 2 3	28	3 2	0 1 4
8	3	0 1 2 2 $\frac{1}{2}$	19	4	0 1 2 $\frac{1}{2}$	29	3 4 1	0 2
9	1	0 2 3 4	20	3 1 2 4	0	30	4	0 3 2 2 $\frac{1}{2}$
10	2	0 1 3 4	21	3 2	0 1 4	31	4 2	0 1 3
11	1	0 4 3 2 $\frac{1}{2}$						

Approximate Central Times when the Great Red Spot passes the Central Meridian of Jupiter.

	h	m		h	m		h	m			
Nov. 16	3	52	P. M.	Nov. 26	2	08	P. M.	Dec. 6	10	20	P. M.
17	9	39	"	27	7	55	"	7	6	11	"
18	5	31	"	28	3	47	"	8	11	58	"
19	11	18	"	29	9	34	"	9	7	49	"
20	7	09	"	30	5	25	"	10	3	41	"
21	3	00	"	Dec. 1	11	12	P. M.	11	9	28	A. M.
22	8	47	"	2	7	04	"	12	5	19	"
23	4	39	"	3	2	55	"	13	11	06	"
24	10	26	"	4	8	42	"	14	6	57	"
25	6	17	"	5	4	33	"	15	2	49	"

Minima of Variable Stars of the Algol Type.

U CEPHEI.

R. A.....	0 ^h 52 ^m 32 ^s
Decl.....	+ 81° 17'
Period.....	2d 11 ^h 50 ^m
Nov. 16	5 P. M.
19	5 A. M.
21	5 P. M.
24	5 A. M.
26	4 P. M.
29	4 A. M.
Dec. 1	4 P. M.
4	4 A. M.
6	4 P. M.
9	4 A. M.
11	3 P. M.
14	3 A. M.

R CANIS MAJ.

R. A.....	7 ^h 14 ^m 30 ^s
Decl.....	-16° 11'
Period.....	1d 03 ^h 16 ^m
Nov. 16	8 P. M.
17	11 P. M.
19	3 A. M.
20	6 "
24	8 P. M.
25	11 "
27	3 A. M.
28	6 "
Dec. 3	9 P. M.
4	midn.
6	4 A. M.
11	9 P. M.
12	midn.
14	3 A. M.
15	6 A. M.

S. ANTLIÆ, CONT.

Nov. 25	3 A. M.
26	2 "
27	2 "
30	7 "
Dec. 1	7 "
2	6 "
3	5 "
4	5 "
5	4 "
6	3 "
7	3 "
8	2 "
12	7 "
13	6 "
14	6 "

ALGOL.

R. A.....	3 ^h 01 ^m 01 ^s
Decl.....	+ 40° 32'
Period.....	2d 20 ^h 49 ^m
Nov. 17	2 A. M.
19	10 P. M.
22	7 P. M.
25	4 P. M.
Dec. 4	6 A. M.
7	3 "
9	midn.
12	9 P. M.
15	6 P. M.

S ANTLIÆ.

R. A.....	9 ^h 27 ^m 30 ^s
Decl.....	- 28° 9'
Period.....	0d 07 ^h 47 ^m
Nov. 15	2 A. M.
19	7 "
20	6 "
21	6 "
22	5 "
23	4 "
24	4 "

R. A.....	20 ^h 47 ^m 40 ^s
Decl.....	+ 34° 15'
Period.....	1d 11 ^h 57 ^m
Nov. 18	11 P. M.
21	11 "
24	11 "
27	11 "
30	11 "
Dec. 3	11 "
6	10 "
9	10 "
12	10 "
15	10 "

Y. CYGNI.

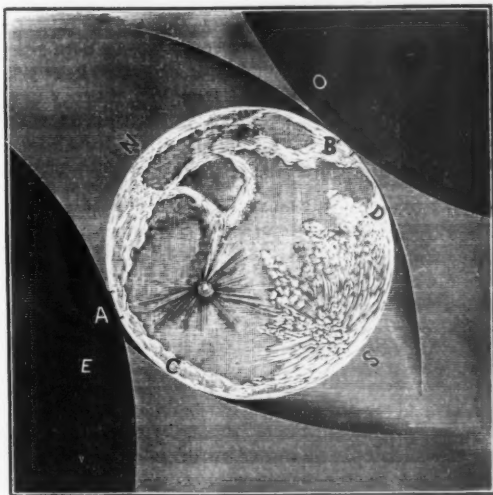
Occultations Visible at Washington.

Date.	Star's Name.	Magni- tude.	IMMERSION.			EMERSION.			Dura- tion.
			Wash. Mean T.	Angle f'm N. P't.	h m	Wash. Mean T.	Angle f'm N. P't.	h m	
Nov. 17...	139 Tauri	5.3	18 32	95	19 27.8	312		0 56	
Dec. 7...	r ¹ Aquarii	5.8	8 22	147	Star 0°.9 S. of moon's limb.				
7...	r ² Aquarii	4.1	9 15	92	10 5.6	205		0 51	
9...	14 Ceti	6.0	11 28	341	11 42.4	314		0 14	
9...	15 Ceti	6.8	12 7	74	13 3.0	229		0 56	
10...	μ Piscium	5.0	12 35	37	13 29.5	269		0 55	
13...	56 Tauri	6.0	13 58	167	Star 0°.9 S. of moon's limb.				
13...	x ¹ Tauri	4.7	16 15	80	17 12.4	266		0 57	
13...	x ² Tauri	6.3	16 16	100	17 11.2	245		0 55	
14...	118 Tauri	5.7	17 40	67	18 31.0	293		0 51	

Phases and Aspects of the Moon.

Central Time.			
	d	h	m
Last Quarter.....	Nov. 23	2	26 A. M.
Apogee.....	" 25	2	48 P. M.
New Moon.....	Dec. 1	5	45 A. M.
First Quarter.....	" 8	11	13 A. M.
Perigee.....	" 11	12	6 P. M.
Full Moon.....	" 15	6	53 A. M.

Total Eclipse of the Moon Nov. 15, 1891. We refer our readers to our last number for the data concerning this eclipse, chart of the stars in the moon's path, and the list of occultations. The moon will enter the penumbra of the earth's shadow at 3^h 36^m central standard time. This phase of a lunar eclipse, is, however, never noticeable. The moon will touch the umbra or the dark part of the shadow at 4^h 35^m. For some time before this a faint shading will have been noticed creeping upon the east side of the



moon, but at this moment it will become much darker at the edge. The accompanying cut will show at what point of the moon's limb the shadow must be looked for. The first contact will be at A. D indicates the last point of the moon to be covered as it enters wholly within the shadow at 5^h 37^m. C marks the points which will first emerge from the shadow at the end of totality, at 7^h 01^m; and B the point which is last to leave the umbra at 8^h 03^m. For a few minutes after this the penumbral shadow will still be visible, but this will fade out long before the end of the eclipse at 9^h 03^m central time.

Minor Planets. Notices of the discovery of the minor planets are resumed from the May issue of this journal:

- No. 310, discovered by Charlois May 16, 1891, Mag.
- No. 311, discovered by Charlois June 11, 1891, Mag.
- No. 312, discovered by Palisa Aug. 14, 1891, Mag.
- No. 313, discovered by Charlois Aug. 28, 1891, Mag. 12.
- No. 314, discovered by Palisa, Aug. 30, 1891, Mag. 11.
- No. 315, discovered by Charlois, Sept. 1, 1891, Mag. 13.
- No. 316, discovered by Palisa, Sept. 4, 1891, Mag. 13.
- No. 317, discovered by Charlois, Sept. 8, 1891, Mag. 13.
- No. 318, discovered by Charlois, Sept. 11, 1891, Mag. 11.
- No. 319, (probably); by Palisa, Sept. 12, 1891, Mag. 13.
- No. 320, (probably); Palisa, Oct. 15, 1891, Mag. 12.

Reappearance of Saturn's Rings. Saturn has been observed with the 15½-inch equatorial telescope of the Washburn Observatory on every clear morning for some weeks past, the observations being usually made by Mr. S. D. Townley, but occasionally by myself. The atmospheric conditions have been rather unfavorable, but on the morning of Friday, Oct. 16, the seeing was good, and the planet was carefully examined by both observers, neither of whom could detect any trace of the rings except the fine dark shadow projected upon the disk of the planet.

Upon the next clear morning, Tuesday, Oct. 20, the planet was again examined under fairly good atmospheric conditions by both observers, who agree that no trace of the rings could be seen at 6^h 50^m local sidereal time, the zenith distance of the planet being then 75°. Twenty minutes later, the seeing having improved somewhat, owing to the increased altitude of the planet, Mr. Townley saw the ring extending out from *each* side of the planet as a very faint line of light, seen by glimpses and with difficulty, but certainly. At 7^h 30^m, although the twilight had become quite bright, I saw the ring on each side of the planet faint and difficult but steadily visible except at intervals of temporary bad seeing. The ring was a trifle more conspicuous on the preceding than on the following side of Saturn. A magnifying power of 145 diameters was used in all the observations.

Washburn Observatory, Oct. 20, 1891.

GEO. C. COMSTOCK.

COMET NOTES.

Comet d 1891 (Barnard Sept. 27, Tempel-Swift?) Two new comets have been discovered since our last issue, both by E. E. Barnard at the Lick Observatory. The first was discovered on the evening of Sept. 27, in the northwest corner of the constellation Aquarius. Sept. 28.6986 GR. M. T. its position was R. A. 20^h 53^m 45.4^s; Decl. -1° 22' 36". This is probably the periodic comet Tempel-Swift, which was expected not far from that part of the heavens. The error's of Bossert's ephemeris, +15^m in R. A. and +3° in Decl., are larger than was to be expected, yet if one plots the predicted path of the Tempel-Swift comet upon squared paper, together with the observed path of Barnard's comet *d* 1891, the similarity is very striking. No elements computed from the recent observations have yet reached us. The comet is very faint, but increasing in brightness. It is almost round with a slight condensation in the center. On Oct. 21 it was just visible in the 5-inch finder of our 16-inch telescope. Its position at 7^h 55^m P. M. central time was approximately R. A. 21^h 04^m 02^s; Decl. +3° 32'. During November this comet will move northeast from Equuleus through Pegasus. We continue the ephemeris of the Tempel-Swift comet which may be used for finding the new comet by subtracting about 14^m in R. A. and 4° in Decl.

		App. R. A.	App. Decl.	log <i>d</i>	Light.
		h m s			
Nov.	19	22 52 01	+ 21 50	9.3247	18.92
	23	23 16 23	+ 24 11	9.3159	19.56
	27	23 43 49	+ 26 24	9.3119	19.68
Dec.	1	0 13 53	+ 28 20	9.3138	19.19
	5	0 45 45	+ 29 49	9.3223	18.06

Comet e 1891 (Barnard Oct. 2). The second comet was discovered by Mr. Barnard on the morning of Oct. 3 in R. A. $7^h 31^m 24^s$; Decl. $-27^\circ 54'$, and is described as a bright comet. It was moving rapidly southward, and is already out of range of northern observers. The comet's position was determined at Lick Observatory on Oct. 3, 4 and 5, and an orbit was at once computed by Mr. Campbell and distributed by telegraph, so that it reached observers in America on the evening of Oct. 6. The following are Mr. Campbell's elements and ephemeris:

$$\begin{aligned} T &= \text{Nov. } 8.75 \text{ GR. M. T.} \\ \omega &= 262^\circ 06' \\ \Omega &= 215 \quad 38 \\ i &= 75 \quad 50 \\ q &= 1.0166 \end{aligned} \quad \left. \vphantom{\begin{aligned} T \\ \omega \\ \Omega \\ i \\ q \end{aligned}} \right\} \text{Mean Eq. 1891.0}$$

Gr. Midnight.	R. A.			Decl.	Light.
	h	m	s		
Oct. 6	7	52	00	$-32 \quad 52$	
10	8	18	00	$-38 \quad 18$	1.05
14	8	46	20	$-43 \quad 08$	
18	9	16	44	$-47 \quad 14$	1.05

Wolf's Periodic Comet is moving southwest through the constellation Eridanus, which is the next southwest of the familiar constellation Orion. The comet is slowly receding from the earth and sun, so that its light is diminishing, but we will be able to follow it for several months yet.

Encke's Comet is out of view behind the sun.

Ephemeris of Comet 1891 (Wolf's Periodic Comet).

(Continued from page 421.)

	App. R. A.			App. Decl.	log Δ
	h	m	s		
Nov. 13	4	35	55	$-8 \quad 06.9$	
14		35	20	$8 \quad 30.5$	9.9207
15		34	45	$8 \quad 53.4$	
16		34	08	$9 \quad 15.7$	9.9249
17		33	31	$9 \quad 37.2$	
18		32	53	$9 \quad 58.1$	9.9295
19		32	14	$10 \quad 18.2$	
20		31	35	$10 \quad 37.6$	9.9344
21		30	56	$10 \quad 56.3$	
22		30	16	$11 \quad 14.2$	9.9397
23		29	36	$11 \quad 31.5$	
24		28	55	$11 \quad 47.9$	9.9452
25		28	15	$12 \quad 03.6$	
26		27	35	$12 \quad 18.6$	9.9511
27		26	55	$12 \quad 32.8$	
28		26	15	$12 \quad 46.3$	9.9573
29		25	36	$12 \quad 59.0$	
30		24	57	$13 \quad 11.0$	9.9637
Dec. 1		24	19	$13 \quad 22.3$	
2		23	41	$13 \quad 32.8$	9.9704
3		23	04	$13 \quad 42.6$	
4		22	28	$13 \quad 51.7$	9.9773
5		21	52	$14 \quad 00.2$	
6		21	18	$14 \quad 07.9$	9.9844
7		20	45	$14 \quad 14.9$	
8		20	13	$14 \quad 21.3$	9.9917
9		19	42	$14 \quad 27.0$	
10		19	12	$14 \quad 32.1$	9.9992
11	4	18	43	$-14 \quad 36.5$	

NEWS AND NOTES.

Maine is very much like Minn. when carelessly written, hence our correspondents will please write the name or abbreviation of our state plainly and so avoid the delay or loss of letters. It is also noteworthy that there are almost as many Northfields in the United States as there are separate states, and it is sometimes true that letters have visited as many as *three* different Northfields in as many different states before reaching the right one.

Quite large space is given to our leader in this issue because the paper is deemed to be one of the most important that can be brought to the attention of our readers, on account of the careful and full statement of principle and method in the use of the spectroscope. We do not know of any source of practical information better adapted to the wants of the student and worker with the spectroscope than this article furnishes.

In our last issue, Wm. H. Knight, whose present address is Los Angeles, California, published a pretty full list of the telescopes of the United States whose apertures were 4 inches or greater. This heavy task was undertaken some time ago at our urgent request, Mr. Knight very well knowing what it meant. He did not expect to get in the first publication all the telescopes that should be in the list, but it was thought that such a provisional list would serve to call the attention of those having instruments not in the list and that they would most likely report them, especially if urged to do so in order to secure an accurate table. We have already received many letters giving just the information desired as far as it goes. Now, if every reader of these pages, will take the trouble to look over the table of telescopes published in the October MESSENGER, and inform us or him of errors or omissions in it, we are sure that Mr. Knight will esteem it a favor in carrying out a piece of useful work which he has undertaken that involves labor and personal expense.

Note on the August Meteors. The August meteors were more numerous this year than at any previous return that I have witnessed, judging from recollection alone.

They first became noticeable about July 27th, and were persistent at least until August 12th, the maximum occurring, August 10th.

On August 9th, one of these meteors of remarkable brilliancy was observed at 15^h in the south. Its path, about 5° long, was vertical. It appeared 4° or 5° east of Alpha Capricorni. The explosion of this object illuminated the mountain for a moment almost as bright as day. It was many times brighter than the maximum light of Venus. A distant trail remained visible to the eye for about one minute. This was examined with the comet seeker, and was seen to twist and writhe into a serpentine form, with numerous bright condensations. It was watched for some time. In passing over the stars, it seemed to have no effect upon either the intensity

or steadiness of their light. (In speaking of this meteor train, I would like to call attention to a paper of mine upon the subject of meteor trains and high atmospheric currents, which appeared in *THE SIDEREAL MESSENGER*, Vol. I., pp. 174-180, since the subject has been recently brought up again in *THE MESSENGER* (see No. 87 for August, 1890, p. 329).

On the 10th, before midnight, the meteors seemed unusually frequent. Many appearing as bright as 2nd or 3rd magnitude stars. On this night, a continuous count from 14^h 15.6^m to 14^h 49.0^m, Mt. Hamilton M. T., showed 95 meteors; all but seven of these belonged to the Perseid radiant. This gives an hourly rate of 160 for the observed Perseids. The eyes were kept fixed on the place of α Persei, and only about one third of the sky was under observation. The majority of the meteors were faint. The display was intermittent. From one to two minutes at a time no meteor would be seen; this quiescence would be followed by a quick succession of meteors, as many as three being seen at once.

The peculiarities were. Intensity of light; rapidity of motion; shortness of path—those seen averaging 4° to 5°. Each left a train covering the entire path and persistent for nearly a second. Meteors with long trains were seen in the west before and after this. During the count, there did not seem to be so many bright meteors as were visible in the first part of the night; and at 16^h there seemed to be a still less number.

On the 11th, fewer still were noticed and a count from 13^h 2^m to 13^h 15^m gave 23 meteors, or at the rate of 106 per hour; they were still seen coming from the radiant as late as 16^h 15^m.

On the 12th a few were seen belonging to this shower.

The 13th was cloudy.

E. E. BARNARD.

Mt. Hamilton, 1891, August 14.

Distribution of the Moon's Heat. Last month we called attention to the prize essay on the distribution of the moon's heat, and its variation with the phase, by Frank W. Very, Allegheny Observatory, Pa., but for want of space we could only make the merest reference to it. As then stated the essay was presented to the Utrecht Society of Arts and Sciences, and obtained the prize in the General Assembly of the Society, held at Utrecht on the 2d of July, 1890. The problem of the variation of the moon's radiant heat with the phase, is attacked, in this paper, by Professor Very, by the aid of an extremely sensitive apparatus known as the bolometer and by a novel method. The plan of work was to form an image of the moon of a little more than one and one-fourth inches in diameter, by means of a concave silvered-glass reflector of 11.93 inches diameter, and 10.29 feet focal length, and to measure, not the heat of the whole of this image, but only that in a limited portion of it, from one-twenty-fifth to one-thirtieth of the area of the apparent disc. The observation being repeated at different points on the moon's disk, and at different phases, gives the material for a series of maps showing the distribution of the heat of this image, and by summation the total heat, at each of the several epochs from the first to the last quarter of the moon.

The sensitive surface of the bolometer was about three-fourths of a square inch, which was covered by diaphragm of white card pierced by a

central circular aperture of a little more than one-fifth of an inch in diameter. Connected with the bolometer is a siderostat by which the image of the moon is kept on the white card, the image being bright enough to show much of the detail of the lunar surface, so that setting of the sensitive surface of the bolometer on any part becomes easy and definite. The heat from that fractional area of the moon's surface that falls on the sensitive face of the bolometer is measured by the deflection of the magnetic needle of a sensitive galvanometer in metallic connection with it. The apparatus which Professor Very used in this work was sufficiently delicate to show a deflection of the needle through nearly 100 millimeter divisions on the galvanometer scale when a small area near the center of the full moon was exposed to the bolometer for measurement. The constancy of an instrument so delicate as this would naturally suggest itself to the reader's mind, and information on this point is given in the early part of the paper.

A series of ten observations of the radiation from a boiling Leslie's Cube, with this bolometer, gave a mean deflection of 342.4 divisions ± 0.6 divisions where the probable error amounted to less than 0.2 of one per cent. In general it seems, that this instrument sensitive as it is, is capable of giving repeated measures on a source of unchanging radiation with an error less than one per cent. of the quantity measured. Of course, it is not meant by this that the constant now referred to does not change in time, that must be expected, but, in this particular the instrumental errors are known, or eliminated by a method of standardizing. It may be added here that the bolometer is not primarily for absolute measurement, yet its indications may be transformed into units of ordinary measure whenever desired. For example, in this research one millimeter division of the galvanometer scale corresponded approximately to a radiation of about 0.000004 small calories per minute on the face of the bolometer, of which only about one-sixth, or 0.0000007 calories was retained by the bolometer strips. By small calorie is doubtless meant the amount of heat necessary to raise the temperature of one gram of water one degree centigrade. The "solar constant" of heat thus figured would be the number of these *small* calories received per square centimeter of solar surface in a minute of time.

This paper next discusses the geometrical representation of distribution of heat in the lunar image, and an algebraic form of four terms is derived, the first representing the varying radiation from the bright path of the moon which it is desired to measure, another, the radiation from space which always has the negation sign and other terms to represent radiations of parts of the instrument and the dark part of the lunar disc. In the use of this mathematical expression it is a profitable study to see how the author applies its terms to obtain an independent measure of the heat radiation of parts of the lunar surface desired. The astronomical, meteorological and instrumental data used in this work extend over a period from Jan. 12, 1889 to April 15, 1889. From a reduction of these, seven maps were prepared showing heat contours of equal temperature on the lunar surface for particular phases, the whole disc of the moon being represented by a circle about 6 inches in diameter. The following final table is of peculiar interest:

Phase-angle from full moon	Total heat	Percentage of total heat at full	Light ac- cording to Zollner	Heat ac- cording to Lord Rosse
-100°	50	14.9		11.4
-90°	63	18.8		15.4
-80°	75	22.3		21.9
-70°	92	27.4	14.4	29.4
-60°	116	34.5	22.3	37.1
-50°	153	45.5	32.1	46.2
-40°	200	59.5	43.7	56.4
-30°	259	77.1	56.8	68.6
-20°	310	92.3	70.9	83.6
-10°	334	99.4	85.5	97.9
-0°	336	100.0	100.0	100.0
+10°	315	93.8	85.5	91.4
+20°	282	83.9	70.9	80.5
+30°	246	73.2	56.8	69.3
+40°	211	62.8	43.7	58.4
+50°	180	53.6	32.1	47.9
+60°	151	44.9	22.3	38.3
+70°	126	37.5	14.4	32.3
+80°	104	31.0		25.5
+90°	84	25.0		19.8
+100°	67	19.9		13.7

The author's final words fittingly close this review:

"This table shows conclusively, first, that visible rays form a much larger proportion of the total radiation at the full than at the partial phases, the maximum for light being much more pronounced than that for the heat.

Next, as has been foreseen from the eccentricity of the heat areas, their greater extension toward the western limb, and the greater steepness of the sunset than of the sunrise gradient, the diminution of heat from the full to the third quarter is slower than its increase from the first quarter to the full.

Finally, there is a fair agreement between these results and those of Lord Rosse which extends even to some minor details such as the attainment of the highest heat a little before the full. This deviation of the maximum from strict symmetry is probably real, and is perhaps attributable to the greater proportion of bright areas in the western half of the moon, the brighter parts, as we have learned, giving a larger radiation under a high sun, than the dark. It is possible that this effect is reversed with a low sun, the dark parts radiating more than the bright, and that the greater heat of the lunar afternoon may be due less to a retention of heat, than to the greater darkness of the region exposed to view at that time. That there must be some retention of heat by the substances of the lunar surface, cannot, however, be doubted in view of the contrast in the heat of polar and equatorial regions under identical illumination, which has been described in connection with the observations of April 15th.

Previous investigations have dealt with the heat produced by the radiation from the entire moon, but the method pursued in the present research has been to study the thermal effect of small portions of the lunar disc, thereby eliciting many new facts concerning the distribution of heat in the moon and its variation through the lunar day for each of these circumscribed regions. The relative radiations of dark and bright surfaces

under high or low sun, and of high and low latitudes, in the lunar morning, afternoon, or noon, have thus been measured, and the accompanying maps present (it is believed for the first time) a picture of the distribution of heat on a planet, where seasons and the climatic influences of land and water must be unknown."

Students' Astronomical Observatory of the State University of Iowa. The following description of the Students' Astronomical Observatory recently established at the State University of Iowa, has been furnished by Professor L. G. Weld, under whose direction the new observatory has been erected and equipped:

The Students' Observatory building is situated upon the University Campus and comprises an upright twelve feet square, and a wing ten by twelve feet. The upright, which accommodates the equatorial, is surmounted by a turret twelve feet in diameter, which rolls with great ease on ten *lignum vitæ* balls. This turret is of the cylindrical form and is covered with galvanized iron.

The wing, in which the transit instrument is mounted, is provided with a clear opening twenty inches wide from north to south.

The building rests upon a solid stone foundation and is heavily framed of thoroughly seasoned and dressed timbers.

Both equatorial and transit are mounted upon insulated piers of stone and brick laid in cement and sunk six feet into the ground.

The Grubb equatorial telescope, which has been moved from the old brick Observatory to this more convenient location, is of five inches aperture, seventy-seven and one-half inches focal length, and is furnished with a driving clock, circles, etc. It has recently been refinished throughout by Mr. M. E. Kahler of Washington. While in his hands the objective was "re-worked," a position micrometer with illumination by electric light, a helioscope, a direct-vision spectroscope, and a diagonal prism were added, and the slow motions and clamps brought down to the eye end. The mounting is very rigid and the telescope is, for its size, a thoroughly efficient instrument.

The transit, by Wm. Würdemann of Washington, is of one and seven-eighths inches aperture and twenty inches focal length. It is an excellent little instrument.

Time is kept by a Seth Thomas clock and a Bond chronometer.

A four-inch portable equatorial by Fitz, and a prismatic sextant and artificial horizon by Pistor and Martins, also belong to the Observatory.

A small chronograph has been ordered from Fauth & Co.

Our object has been simply to establish an Observatory which will meet the requirements of students in astronomy.

L. G. W.

Iowa City, Iowa, October 8th, 1891.

Black Transit of Jupiter's III Satellite. On the evening of Sept. 24, I witnessed what appeared to be a "black transit of Jupiter's III Satellite.

L. G. W.

Erratum. On page 407, No. 98 of THE MESSENGER, in place of v read r , and in place of r read v .

Professor Frank H. Bigelow of the Nautical Office, Washington, D. C., has been assigned to the study of cosmical and terrestrial magnetism, in its relations to meteorology, in connection with the U. S. Weather Bureau, Department of Agriculture, Washington. His work will be facilitated by the aid of publications on the subjects of solar and terrestrial physics and meteorology. Professor Bigelow will be a strong man in this new place.

Regarding my list of telescopes published in your October issue I beg to submit the following criticism made by Mr. J. A. Brashear.

... "First, you say the Clarks are now grinding an object glass of 40 in. Now the facts are, there has never been any contract made for the glass and only one disc is in the shop of the Clarks—in the box as it came from Mantois. Only \$50,000 has been subscribed and that, I think, on condition that the balance to build the mounting, Observatory, and road to the top of Mt. Wilson, estimated to cost \$500,000 [should be subscribed]. ... Then they might have to wait ten years for the mate of the disc, for Mantois told me in Paris when I saw the lump of glass from which the disc was made that it was a stroke of good fortune to get such a disc, but while he hoped to get a mate to it, it was a matter of great uncertainty."

"Second, you quoted Smithsonian Physical Observatory as having a 20 in. Grubb Refractor while the facts are the instrument was a 20 in. Grubb Siderostat, the great mirror of which (flat) was made at our place. Professor Langley has a 20 in. mirror of 90 ft. focus and a 20 in. mirror of one metre focus which were made at our place for special work in Professor Langley's determination of unselective absorption of solar energy."

Mr. Brashear also calls my attention to the fact that I did not include in my list some telescopes with upwards of 6 in. aperture. But the heading of my table "Some Telescopes" shows that I was aware that my list was not complete.

WM. H. KNIGHT.

A Non-Interfering Break-Circuit for Clocks. In the application of the electric break-circuit to clocks not provided with the gravity escapement, there appears to be some prejudice, on the score that it may slightly interfere with the performance of the clock, and that it is not desirable for the clock itself to do anything in the way of "key manipulating." The following arrangement experimented with by the writer appears to do away with this objection. A microphone is made, consisting of a piece of arc amp carbon about four inches long, and pointed at the ends, loosely held between two small pieces of carbon with recesses to contain the ends of the larger piece, the whole to be mounted on a base of seasoned wood and fastened to the side of the interior of the clock case as high as convenient, the higher the better, and with the longer carbon vertical. Some form of gravity battery is then connected up with the microphone and a relay; and great care is to be taken that any splices in the wire are well scraped twisted and soldered, and further that all connections are firmly made.

The armature of the relay is to be so adjusted that it approaches the magnet cores as closely as possible without touching, say one-thousandth of an inch; and its play must be *vanishingly* small. The adjusting spring is now to be strained up, and if the relay cannot be made to break with the

clock beat, the battery must be diminished by a cell, or a stronger spring used; in any case quite a tension on the spring is necessary.

All the conditions being properly fulfilled it will be found that the relay breaks in exact unison with the beats of the clock, and this fact may be taken advantage of to compare for difference of personal equation in the two cases where the eye and ear and chronograph methods are used. It is to be noted that no part of the line wire is to be outside of the Observatory, or subject to any possible swaying contact, and it would be well for all wires to be covered and paraffined.

F. G. BLINN.

East Oakland, California.

Origin of Comets. In a recent letter, W. H. S. Monck of Dublin, Ireland, calls attention to some points of interest about the origin of comets. It will be remembered that Professor Newton of Yale University, some time ago, examined the theory of Laplace in regard to the origin of comets, and decided that that noted author was right in concluding that these erratic bodies are visitors from extended space, instead of being members of the solar family in the matter of origin as was claimed by Kant's theory. One particular fact that weighed in this judgment was the large preponderance of those comets whose orbits have high inclinations as compared to the ecliptic. Mr. Monck remarks that on examining Kleiber's orbits this preponderance disappears, and the theory of Kant seems to be indicated by the meteoric orbits if computers have correctly represented them.

Comets Swift and Wolf. Under date of October 14, E. E. Barnard of Lick Observatory writes: "I have secured some good positions of Swift's Comet which I rediscovered Sept. 27. It was so far from its ephemeris place, that, at first, I was uncertain whether or not it was the long-expected comet for which I had made careful search for over three months." Mr. Barnard also speaks of observations of Wolf's Comet as it passed over some of the stars of the Pleiades. He says Mr. Burnham's measures show a slight change in $\Delta\delta$, in measuring the difference of declination of 21 Asterope and 22 Asterope at nearest approach by the aid of the 36-inch refractor. Does this indicate a refraction of the star's light as it passes through the comet?

Fog Bow. On the morning of August 31, eight minutes before seven o'clock, a fog bow was seen at Northfield, Minn. Its highest point was nearly west and about 30° in altitude, and its general width was about 5° . There was a little of the reddish brown color near the horizon on the outer edge. Ten minutes later the whole bow was brighter and better defined. On the inside of the curve was a dark band about three degrees wide. There were trees 300 feet away in the direction of the horizon, and the color was seen on them for the whole width of the bow which was at this time about eight degrees, apparently, and a blueish shade was the color of the inner border, while the outer was a stronger red. It was also noticed that this belt of color could be traced on the ground, at most favorable times, from the foot of the bow on each side nearly to the point where the observer stood. But a small portion of the circle was wanting;

a part of it appeared to lay on the ground, the remainder on the haze of the sky, and the observer in the circumference. The cause of the bow was the light of the sun shining through a fog (east of the observer) rising rapidly from a broad valley in that direction. The unusual thing about it was the appearance of the observer on the circumference of the bow, when in fact he must have been at the center of the real phenomenon.

Mr. Blinn's Mode of Time-Signals. Elsewhere will be found a suggestive mode of communicating clock-beats to electrical lines without any manner of actual contact with the clock train. There is, doubtless, more in the suggestion than appears at first sight, for Mr. Blinn has tried it, and therefore knows whereof he speaks. The fact that delicate adjustment seems necessary to ensure constancy of the service may not prove so great a drawback after all when the apparatus is well made. Time keepers will look into this suggestion with interest.

The Annual Parallax Oeltzen 11677. Dr. Julius Franz, of Königsberg has favored us with a copy of his work on the annual parallax of Oeltzen 11677 determined by the aid of Königsberg heliometer and the results, published only a short time ago, are:

$$\pi = + 0''.10 \pm 0''.01$$

In light years 29.6 to 36.2

Yale University 28-inch Refractor. Some of our readers may wonder that Mr. Knight's list of telescopes should credit Yale University with a refracting telescope of 28 inches aperture, when in fact that institution has no such telescope at the present time. The statement of the case is substantially this: Fifteen years ago, the late Professor Lyman purchased a 28-inch disc by Chance, to be used in making a 27-inch lens, and that disc is now said to be in Clarke's safe, Cambridgeport, but the other disc to match it has never been purchased, nor has work on the telescope mounting ever been ordered so far as we know. Professor Lyman expected Mr. Winchester to furnish the telescope, but that friend of the University died without doing more than to authorize the purchase of the single disc. In the light of these facts, it does not seem fair to credit Yale University with a telescope larger than that of Princeton, University of Virginia, or Harvard College Observatory. It certainly was not Mr. Knight's intention to do this injustice, or ours in printing the table. There is possibly a grain of excuse for us in not looking up this matter more carefully beforehand, when we remember that the 28-inch Yale telescope figures at the head of the list in Johnson's Encyclopedia, and in the list given in Newcomb's Popular Astronomy, it is named as "under construction" with the Lick and Pulcowa telescopes.

BOOK NOTICES.

College Algebra. By Webster Wells, S. B., Associate Professor of Mathematics in the Massachusetts Institute of Technology. Publishers, Messrs. Leach, Shewell & Sanborn, Boston and New York.

In 1890 Professor Wells published a college algebra, very complete in subject matter, and so far as noticed in a hasty review, in excellent ar-

rangement for class use in college or school of technology. The first eighteen chapters of the book are arranged for the convenience of those who wish to review that part of algebra which precedes the subject of quadratics, and hence theoretical parts of the themes there treated are purposely omitted.

The book begins in formal way with the subject of quadratics treated in the ordinary way, after which is a good discussion of the theory of quadratics. Illustrative problems follow, and a fuller consideration of how the quadratic equation can be used to solve examples involving equations of higher degrees. The treatment of logarithms and their applications is prominent and useful for aid to the higher mathematics; so also is the subject of probability, continued fractions, series, determinants, and especially the theory of equations. There is also an interesting appendix giving a demonstration of the fundamental laws of algebra for pure, imaginary and complex numbers that will attract the attention of teachers of mathematics, and students curious to know something of the methods of reasoning and operations of imaginary numbers.

Recently this book has been bound, omitting the first eighteen chapters (the review part), presenting only the College Algebra proper. The publishers, as they always do, have done their part neatly and substantially.

An Introduction to Spherical and Practical Astronomy. By Dascom Greene, Professor of Mathematics and Astronomy in the Rensselaer Polytechnic Institute. Publishers, Messrs. Ginn & Co., Boston. pp. 150.

This new book deserves the attention of teachers of practical astronomy, and also that of students looking forward to extended study in the same branch. It will be found useful because it aims to give the essentials in principle and method concerning the more common operations in practical astronomy in so plain and direct a manner that a student without practice may easily start in this kind of work and soon gain confidence in himself and his mathematics so as to go on to higher works and more difficult topics, and master them independently. The first chapter is concerned with definitions and spherical problems which are to be performed by the general formulæ of spherical trigonometry applied to the celestial sphere. In adapting the formulæ to ready computation by logarithms, the neat expedient of the auxiliary angle is used in the same way as is done in the standard works on astronomy. The proof that the assumptions of these auxiliary angles in a given case are consistent with the notation used, as exemplified in Article 36, pages 10 and 11, is very simple, neat and direct. The second chapter considers the conversion of time and the hour-angle. The relation of sidereal and mean solar time is well stated, and the precepts for the conversion of one kind of time into another, through the aid of auxiliary tables, is made so plain that the beginner will not be confused. So much can not be said of most texts in use for converting time in the Observatory. Chapter third discusses the transit instrument, giving a description of the instrument, its adjustments, and its uses in observation. In the latter part of this chapter, the correction for transit observations is given fully as it ought to be. The meaning of the terms of the formulæ is shown by a geometrical figure, and Bessel's, Hansen's and Mayer's formulæ are derived in a way to interest the reader and to give him clear under-

standing of the nature of instrumental errors and the method of measuring them. Chapter four treats of the sextant, and chapter five tells how to find time by this instrument as well as by the transit instrument. Then follow methods for finding the differences of longitude between two places by telegraph, transportation of chronometers, and by moon culminations, finding the latitude by six different ways; finding the azimuth of a given line, and a study of the figure and dimensions of the earth. In an appendix of thirty pages is found a statement of the method of least squares, and tables of refraction and for computing the reduction to the meridian. We are sure this book will fill a place of felt need, and it is commended on account of its merits.

Woodbridge School Essays Number One. Theoretical Astronomy. Dynamics of the Sun. By J. Woodbridge Davis. Published by Messrs. D. Van Nostrand Company, 1891. 156 pp. Quarto form.

We have been much interested in a hasty reading of number one of the Woodbridge School Essays in the line of theoretical astronomy. A want of time for it has prevented a careful study of this number, as was our choice under more favoring circumstances, yet we are pleased to give our impressions thus obtained.

The order of topics in this number is: Matter—Gravity—Heat; The Outlying Atmosphere; The Quiescent Atmosphere; The Solar Atmosphere; Planetary Atmospheres; Planetary Magnetism; Cometary Atmospheres and the Index.

Under the head of matter, gravity and heat, the author begins by assuming a free body in space supposed to consist of some mixture of solids, liquids and vapors with some quantity of heat. A spheroidal form, density, temperature, pressure, rigidity, and other conditions follow from the action of its own inherent forces.

From knowledge of these forces it is possible to form typical equations and discuss the varying conditions of this hypothetical body in a very direct and definite way, so that the reader may easily follow the development of the argument. This is done under five different forms represented by the letters A, B, C, D, E. As an illustration of the condensed form of the argument in its final statement we copy that belonging to A:

Dynamic Equilibrium—Progressive.

Vapor and mist descending.

Heat < Gravity.

$f''(\tau_0) > f'''(\tau_0)$

$[f''(\tau) > f'''(\tau)]_0^{-a}$; Condensation.*

$[f''(\tau) < f'''(\tau)]_{-a}^{\infty}$; Limpidity.

τ_0, m_1, g_0 , increase.

τ, v, m', Q', I , are negative.

The meaning of the letters above are respectively:

τ_0, τ , the absolute temperature of any concentric stratum of atmosphere.

f'', f''' , are functions of τ .

* Limits are in values of time for conditions A, C, D, E; in values for distance B.

t , the time required for a particle to flow from the nucleus of the body to this stratum.

v , is the velocity of a particle of this stratum.

Q is the quantity of thermal energy expended in any time.

m , m' are respectively the mass of the nucleus, and the quantity of matter vaporized per second.

g_0 is acceleration due to gravity due to this stratum.

I is the quantity of thermal energy expended in molecular or atomic work.

This is intended only to give the merest outline of the way these important studies are carried forward by the author, and of course will be most interesting to those who are accustomed to the statement of argument in this way by mathematical symbols. We have not the space to consider the results reached by the author in these essays, but hope to give full statements of them later. We are sure this work will receive the prompt and deserved attention of scholars in various lines of science.

Pictorial Astronomy for General Readers. By George F. Chambers, F. R. A. S. Publishers: Messrs. Whitaker & Co., 2 White Hart Street, Paternoster Square, London, England. 1891. pp. 268. Price 4 shillings.

The writer of this new popular book in astronomy is too well known to our readers to need any formal introduction; and it does not seem strange that he should write such a book in view of all the other laborious and difficult work in the line of standard authorship through which he has passed during the last score of years, for such experience is the most fitting school in the world for elemental instruction in the same things. The table of contents follows the order of the author's higher works, beginning with brief reference to the solar system, then the sun; planets collectively, individually; the phenomena of eclipses, occultations and transits; comets, meteors, stars, clusters and nebulae; and then gives interesting chapters on the telescope, the spectroscope, as applied to astronomy, and the history of astronomy, concluding with the usefulness of astronomy. We have thought that chapter on the history of astronomy so well considered and presented that we have copied it entire in this issue. We also think it a fair sample of the work done in preparing this new book. Our readers will be able to judge of its merits for themselves. The text is accompanied by 134 good illustrations and followed by tables of the planets and satellites, giving a large amount of useful data, and by catalogues of celestial objects for telescopes of three inches aperture, clusters and nebulae, and other miscellaneous objects.

Plane and Solid Geometry. By Seth T. Stewart, A. B. 12mo. Cloth, pp. 416. Price by mail \$1.12. Publishers, American Book Co., Chicago.

Among the things to attract attention in this new book are the facts that each book is preceded by a synopsis of its contents, the careful typographical arrangement of the page, the large number of original exercises; definitions appearing as needed; theory, figure and demonstration all in easy sight; and that in the solid geometry the figures are well shown in perspective. The book is in clear type and tastefully and substantially bound and at reasonable price.

Six Place Logarithmic Tables, together with a Table of Natural Sines, Cosines, Tangents, and Cotangents. Prepared by Webster Wills, A. B., Associate Professor of Mathematics in the Massachusetts Institute of Technology. Publishers, Messrs. Leach, Shewell & Sanborn, Boston and New York.

These tables are arranged in the usual way, on a large open page, using a good figure for ready and continued use by the computer. They compare very favorably with any six place figures we know of.

SMALL TELESCOPES FOR SALE.

We have had so much correspondence about small telescopes during the last year that we have decided to devote one or more of our advertising pages to information of this kind, especially in regard to second-hand telescopes, in the interest of those who wish to buy or sell such instruments. Naturally enough persons who wish to buy such telescopes are timid lest they be cheated in the operation. We cannot recommend a telescope that we have not seen and so we have been unable, in many instances, to help persons in this way who really need aid.

Now, we make this suggestion: That any person having a good, second-hand telescope who wishes to sell it, may try to do so through our agency, for new and second-hand instruments. The telescope should be sent to "Goodsell Observatory of Carleton College, Northfield, Minn.," transportation prepaid, and we will give it a careful examination and publish an account of its condition and the owner's terms of sale.

In case of sale we will charge ten per cent. for all values under \$500. For values over \$500 special arrangements will be made. If an instrument is not sold within four months it will be returned at owner's expense and no charge will be made for examination and advertising. If the owner still wishes to keep his instrument in the agency for sale, special arrangements to that effect may be made. Correspondence is therefore solicited from all persons wishing either to sell or to buy second-hand astronomical instruments.

FOR SALE.—A Second-Hand Tripod Mounting for a small telescope is offered for sale at this office for \$25.

FOR SALE.—One of the finest clocks ever brought to this country. Suitable for an observatory. Correspondence solicited. Address
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Dr. W. Pratt of London says that married life is by far the most healthy and furnishes a startling array of figures to prove it. In 1,000 married men of 25 to 30 years of age there are 6 deaths; 1,000 bachelors furnish 10 deaths, and 1,000 widowers 22 deaths. The widowers, it seems, have the worst of it, but they have the consolation of having been married, while the bachelor finds the days a trifle chilly. Married life is by all odds the more sensible, as all know; so young folks get married. And when you do, make your wedding tour over the Saint Paul & Duluth Railroad,—the Duluth Short Line,—which is the people's popular route to and from the double twins of the Northwest—St. Paul, Minneapolis, Duluth and West Superior. This line is noted for the superior excellence of its equipment, the rapidity of its trains, the convenience of its hours of arrival and departure, the beauty of its scenery and the splendid character of its terminals. Always take the Duluth Short Line. Information cheerfully furnished by ticket agents at all points, or upon application to GEO. W. BULL, General Passenger Agent, or GEO. C. GILFILLAN, Asst. G. P. A., St Paul, Minn.

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Calendar.

Examinations to enter the College Sept. 8, 1891.

Examinations to enter the Academy the first afternoon of each term.

Fall Term begins Wednesday, Sept. 9, and ends Tuesday, Dec. 22, 1891.

Term examinations, Monday and Tuesday, Dec. 21 and 22, 1891.

Winter Term begins Tuesday, Jan. 5, and ends Wednesday, March 16, 1892.

Term Examinations, Tuesday and Wednesday, March 15 and 16, 1892.

Spring Term begins Tuesday, March 29, and ends Thursday, June 16, 1892.

Examinations to enter the College, Friday and Saturday, June 10 and 11, and Tuesday, Sept. 6, 1892.

Term Examinations, Monday and Tuesday, June 13 and 14, 1892.

Anniversary Exercises, Saturday to Thursday, June 11 to 16, 1892.

Fall Term begins Wednesday, Sept. 7, 1892.

JAMES W. STRONG, PRESIDENT.

WALES AND BACCARAT.

Have you ever figured out the probable age of the Prince of Wales? Come to think of it, he is no tender spring chicken. He was born on Monday, Nov. 9, 1841, and therefore is now a few days beyond the half century mark, and at an age when he certainly ought to give his mind to more serious matters than the "kitty," "flushes," "fulls," "pairs" and other frivolous things, especially the ramifications of baccarat of the brand used at Tranby Croft. Albert Edward made a mistake in being born to the purple and the crown. He should have been an American Westerner—say a Minnesotan—and his talents would not have been hidden under a stack of poker chips and baccarat counters. As it is he knows not what he has lost. But Minnesota survives and the Saint Paul & Duluth Railroad—known far and wide as the Duluth Short Line—is still the best line for tourists traveling from St. Paul and Minneapolis to Duluth and West Superior and intermediate points, for it provides the finest equipment, the fastest trains and the most convenient schedules, besides offering the inducements of solid comfort. For information address GEO. W. BULL, General Passenger Agent, or GEO. C. GILFILLAN, Asst. G. P. A., St. Paul, Minn.



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The popularity of the line is attested by the fact that notwithstanding the strongest kind of competition of old and new lines, the Chicago, Milwaukee & St. Paul Railway continues to carry the greater proportion of all the business between Chicago, Milwaukee, St. Paul and Minneapolis. It is the best patronized route between Chicago, Council Bluffs and Omaha to and from all points in Wisconsin, Minnesota, Dakota and Iowa, and its Kansas City and St. Joseph line has taken equal rank with the other lines leading to and from the Southwest.

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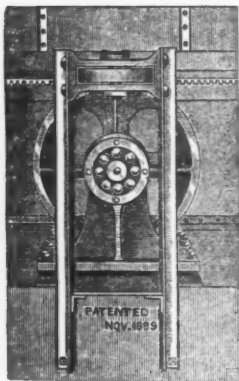
The Sidercal Messenger.

A DISTRESSING FAMINE.

Not a famine in Ireland, nor in India, but right here in the Northwest and right at the close of a season of surpassingly bountiful crops. Neither is it a famine of bread, but a famine of cars, which, under some circumstances, is almost as serious for when cars are scarce it is hard to get supplies of coal, etc. The extent of the crops throughout the West and Northwest has created a heavy demand for cars, and the supply thus far has scarcely been equal to the demand. However, in the matter of passenger equipment the Saint Paul & Duluth is never at a loss to give its army of patrons just exactly what they need, and to that fact is due the increasing popularity of the Duluth Short Line. This popular route extends from the Twin Cities to the head of the big lake, with numerous branches, and is the line all should take when traveling in that direction, for it has splendid trains running on quick time over an admirable roadbed, and makes close connections for all points at unequaled terminals. Circulars, time-tables, etc., cheerfully furnished upon application to ticket agents, or to GEO. W. BULL, General Passenger Agent, or GEO. C. GILFILLAN, Asst. G. P. A., St. Paul, Minn.

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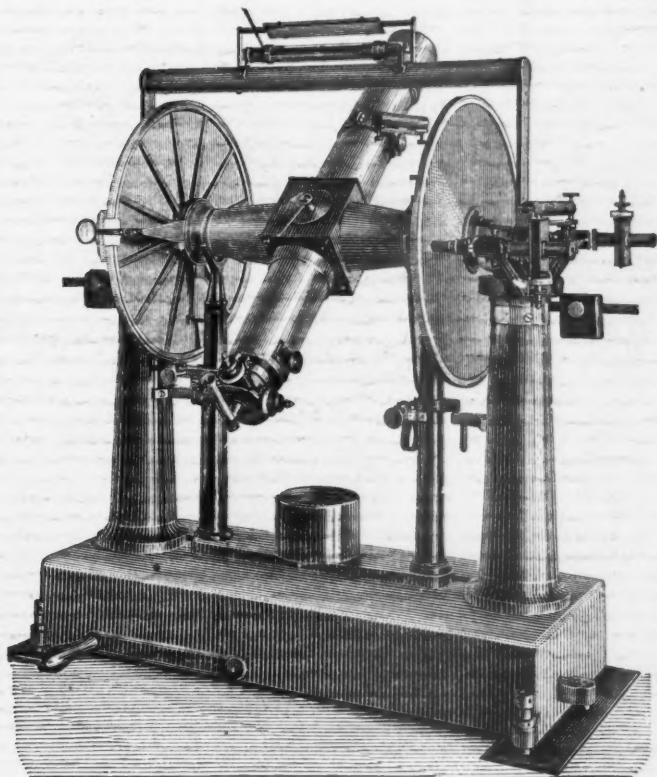
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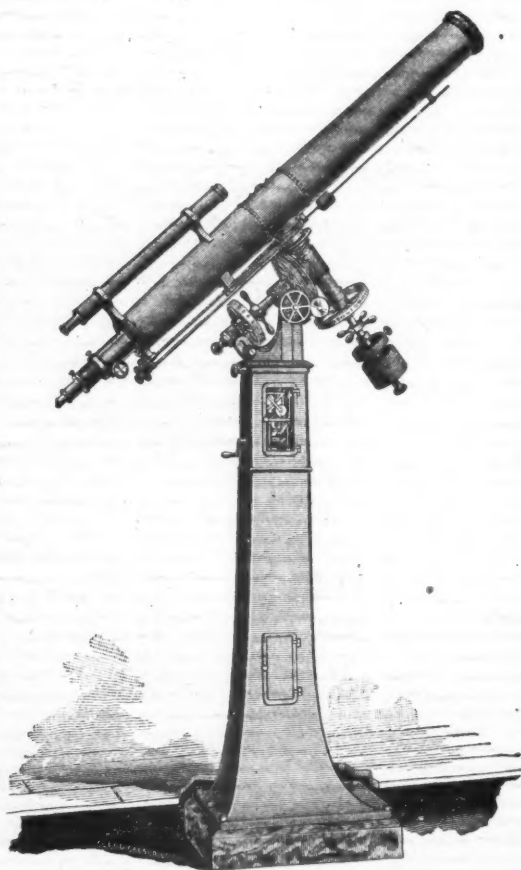
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